

europ physics news



BULLETIN OF THE EUROPEAN PHYSICAL SOCIETY

No. 4 July 1969

The Growth Points of Physics

The following reviews cover the scientific content of the Inaugural Conference of the European Physical Society held in Florence on 8-12 April 1969. They concentrate particularly on the parallel sessions which were held in five sections. The sections and the authors of the reviews are as follows :

Astronomy, Astrophysics, Cosmology and Relativity	D. W. Sciama
Nuclear and Elementary Particle Physics	G. H. Stafford
Physics of Condensed Matter	S. F. Edwards
Atomic, Molecular and Plasma Physics	C. M. Braams
Quantum Electronics and Optics	A. Kastler

Astronomy, Astrophysics, Cosmology and Relativity

One point above all emerged from the sessions on astrophysics, cosmology and relativity, namely that the recent flood of discoveries in these subjects has led to close links being forged with the rest of modern physics. In particular, newly discovered celestial objects provide a testing ground for the more extreme predictions of modern theory, and in many cases exhibit extreme behaviour of an unexpected kind.

The most recent illustration of this is provided by the pulsars. These remarkable objects were described at a plenary lecture by A. Hewish, whose team at the Cavendish Laboratory, Cambridge, was responsible for their discovery just over a year ago. The "clockwork" mechanism of a pulsar is now generally agreed to be the rotation of a neutron star, but the origin of the pulses is not understood (although it probably involves coherent radiation emitted by relativistic electrons).

The physics of neutron stars was described by E. E. Salpeter who spoke about highly condensed matter in stars and by R. Penrose who explained the nature of gravitational collapse according to general relativity. A neutron star is an object of about a solar mass which can have a radius of only 10 kilometers and still be in a static and stable configuration. At such high densities (about 5×10^{14} gm cm⁻³) the stellar material no longer consists of protons and electrons; the Fermi energy of the electrons would be so high that it is energetically favourable

for inverse beta decay to convert most of the material into neutrons. The existence of such a stable state has been known theoretically for a long time, but it was not clear that such a state would be reached by actual stars at the end-point of their evolution. Now it appears that neutron stars probably do in fact come into existence, in some cases at least, in association with a supernova outburst as in the Crab nebulae. This discovery will undoubtedly stimulate physicists to make further studies of their properties.

Relativists too will be stimulated because a neutron star whose mass exceeds a few solar masses cannot form a static configuration. Such a neutron star would collapse under its own gravitation and, according to some recent theorems described by Penrose, would be expected under most circumstances to end up in a singularity. The Galaxy may contain many such "black holes".

The relatively old-fashioned topics of radio galaxies and quasars were described by L. Woltjer. For the physicist their most remarkable property is the scale and violence of the explosions which give rise to such objects. In some cases it seems likely that well over 10^{60} ergs is explosively released into relativistic particles and possibly also into relativistic bulk motions of thermal gas. In other words an energy of at least 10^6 solar rest-masses, and possibly 10^8 solar rest-masses, is explosively released. Since a large galaxy contains about 10^{11} solar rest-masses, it will be seen that a substantial fraction of the rest-mass energy of a whole galaxy can be ra-

pidly converted into relativistic particles. The relativistic electrons emit a powerful flux of radio, optical and perhaps even X-rays by the "synchrotron" process (magnetic bremsstrahlung) in the ambient magnetic field, in some radio galaxies on a linear scale comparable with that of a cluster of normal galaxies. The mechanism of the explosion, the conversion of the energy into relativistic particles, and the origin of the large-scale magnetic field are not understood.

For the cosmologist the quasars have a special interest in that they often have spectacular red shifts. The largest red shift so far recorded is $\delta\lambda/\lambda = 2,36$.

Most astronomers believe that these red shifts arise from the expansion of the Universe; if they are correct then the Hubble law would imply that some of the quasars are by far the most distant objects yet detected.

The most overtly cosmological lecture was given by G. B. Field, who talked about the cosmic microwave background. G. Gamow predicted in 1948 that if the elements heavier than hydrogen were formed by thermonuclear reactions in the "hot big bang", then the Universe to-day should be filled with black-body relic radiation at a temperature of a few degrees absolute. Recent calculations have shown that in fact only helium can be built up to the observed abundance in this way. Heavy elements are probably formed in the explosions of massive or supermassive stars, and some of the light elements by spallation reactions at stellar surfaces, as explained in another lecture by E. Schatzman.

A black-body radiation field at a few degrees absolute would be more intense than any other known source in the Universe at microwave frequencies. Professor Field described the present state of the observations, which stem from the accidental discovery by Penzias and Wilson in 1965 of an intense background at 7 centimetres (with an effective temperature of 3°K). Measurements now exist from 70 centimetres to 3 millimetres and there is also an indirect estimate at 2.5 millimetres from the observed rotational excitation temperature of interstellar CN. A 3°K black-body spectrum would peak at about 1 millimetre, where atmospheric absorption is, unfortunately, large. One (anomalous) submillimetre rocket measurement has so far been made and more rocket measurements are planned. The weight of observational evidence is in favour of a black-body spectrum at 3°K, but most of this evidence refers to the Rayleigh-Jeans region of the spectrum and a final decision awaits reliable measurements near the peak.

The existence of a universal black-body radiation field would also be of great importance to the astrophysicist, because such a field would seriously degrade cosmic-ray protons, electrons and γ -rays. The electrons in turn would convert black-body photons into X-rays (via the Compton process), and in some cases these X-rays may have been detected in rocket flights already made by X-ray astronomers.

We may summarise all these developments by saying that high-energy astrophysics is now a subject in its own right, and one in which our knowledge is increasing with explosive rapidity. It is altogether appropriate that a Section should have been devoted to it at the Inaugural Meeting of the European Physical Society which concerned itself with the Growth Points of Physics.

Nuclear and Elementary Particle Physics

The five sessions covering Nuclear and Elementary Particle Physics span-

ned an energy range of about 12 orders of magnitude from 10^{-2} to 10^{10} electron volts and three of the four fundamental interaction fields known to exist in nature, the Weak, the Electromagnetic and the Strong, with strength constants spanning 14 orders of magnitude.

One of the highlights of the meeting was the lecture on the Status of Quantum Electrodynamics given by F.J.M. Farley. Of the three interactions the Electromagnetic is certainly the best understood in the sense that through quantum electrodynamics (QED) we have available a set of rules which enable us to make calculations on a variety of electrical phenomena with great accuracy and a large number of very accurate and refined experiments now appear to confirm all the basic theoretical predictions. However, these experiments only test the theory to energies of up to a few GeV — indeed there are infinities in the theory at high energies (or equivalently at very short distances) — so what happens at very short distances is the main objective of the current experimental work.

This experimental work can be divided into two main areas: (a) high energy processes directly involving high momentum transfers and (b) very accurate experiments on low energy phenomena such as the Lamb shift and the anomalous magnetic moment of the electron and the muon. So far the high energy experiments show no discrepancies up to momentum transfers corresponding to values of $g^2 \leq (5 \text{ GeV})^2$, that is, distances of 4×10^{-15} cm.

The energy splitting between the $2S_{1/2}$ and $2P_{1/2}$ states of the hydrogen atom, the Lamb shift, is also a very sensitive test of the theory, because it arises entirely from high-order effects in QED. At the level of a few parts in 10^4 , there is at present a discrepancy of about three standard deviations between theory and experiment. If this discrepancy stands the test of further experimental investigation it will illustrate how a careful experimental investigation based on

an established theory can lead to quite unexpected results. For example, R.C. Barrett et al. and, independently, D.R. Yennie have suggested that if the charge distributions around the proton had a weak positive halo with a characteristic range of 8 fermis and an effective charge about 1% of the proton charge, theory and experiment could be reconciled. This halo could be due to an undiscovered heavy photon with a mass of about 50 electron masses universally coupled with an effective charge equal to 0.01 of the electronic charge.

Once there exists a reliable theory such as QED, ingenious and indeed aesthetically satisfying experiments can be devised to check and extend its validity. Examples of this are those experiments designed to determine the magnetic moment of the electron. Deviations of the electron g-factor from 2 at the level of a few parts in a million are important in the QED calculation of the Lamb shift.

As has been pointed out many times the lepton spectrum is very odd, consisting as it does of the massless neutrino, the electron, and the muon with a mass 200 times that of the electron. Many attempts have been made to detect whether the muon is just a heavy electron or whether it suffers any interaction not experienced by the electron. The beautiful experiments on the gyromagnetic ratio of the muon performed at CERN show a deviation between experiment and theory of (450 ± 270) parts per million. Cautiously therefore it should be stated that there appears to be no new field coupled to the muon, but clearly even more precise experiments are called for. Indirectly, these muon experiments provide the best current evidence for the validity of QED at short distances.

Mention of the muon leads naturally on to the Weak Interaction, the mechanism involved in the decay of the elementary particles. The nature of the Weak Interaction is far more complicated than the Electromagnetic and it is not surprising therefore that it is far less well understood. At the present time the experimental and

theoretical fronts are fairly static, the last major shock being the discovery of CP violation some five years ago in the decay of the long-lived neutral K mesons. The source of this CP violating effect is still not understood in spite of a great deal of experimental work. The trouble is that the experiments are very difficult to do and there is still an unfortunate lack of agreement between the available experimental results. So, although there was nothing new reported at the meeting in the field of Weak Interactions, one gets the impression that a lot is bubbling just below the surface.

There are so many odd things about the Weak Interaction. For example, there is the question of the muon itself. We know that it is not an excited state of the electron, because the accurate measurement of its magnetic moment tells us it is an elementary particle without any internal structure and it even has its own neutrino. Nor have we yet discovered experimentally the particle, the intermediate boson, which is needed to mediate, that is, act as the carrier of the force. The Weak Interaction is also not spatially symmetrical — it violates parity.

And so on to the Strong Interaction where, out of a wide range of possible growth points, H. Lipkin was invited to talk on the Spectrum of Hadrons. He was right to point out that in spite of years of toil it was not much of an exaggeration to state that there was no theory and little in the way of experimental results. Unfortunately too, as he pointed out, we have had to do our experiments in the wrong order. We know the fine structure — the multiplets — but the spacing between the multiplets is still not known. Higher energies are required. It is as if we only knew the fine structure in atomic spectra and from it we were trying to derive electron configurations!

Theorists are excited about the newly developed concept of "duality" which relates low energy resonance formation to the high energy scattering phenomena. The idea is that a scattering amplitude can be expressed either as a sum of resonances (character-



ised by the quantum numbers : I isotopic spin, B baryon number and Y hypercharge) or as a sum of exchanged Regge trajectories whose description is given in terms of the kinematical variables s , t and u . There is increasing belief that these descriptions are equivalent.

Lipkin's advice to experimentalists, particularly in connection with the search for the mysterious quark, was that they should follow their noses. The simple quark model has, of course, had surprising success but one experimental result which causes concern — or pleasure depending on one's point of view — is the splitting of the A_2 meson. Indeed, Lipkin felt that the slide shown by Cabibbo at the 1966 International Conference on High Energy Physics, with suitably modified captions, expressed the situation rather well (see Figures). If the A_2 meson is a doublet, many of the established resonances should also show a doublet structure and these effects could be explained only by

adding complication to the simple quark model.

Limitations in space have made it possible to comment on only a few of the topics discussed. Another author might well have selected a different set of topics, for, over the whole energy range from fission to the high energy collisions of hadrons, the subject is alive and bursting with possibility.

Physics of Condensed Matter

"Condensed Matter" is a subject of great interest in its own right which also constitutes the major bridge between physics and industry. With a wide range of topics to choose from, many had to be omitted, but the Conference attracted leading speakers, who gave a very wide coverage, and had many of Europe's leading physicists present to enliven the discussions.

The plenary session was given by Sir Nevill Mott who talked on "Elec-

trons in Conducting and Non-Conducting Materials". This centred on the key problem of what factors, when a material could be either a metal or an insulator, decide which it does in fact become. The simplest models of metal and insulator simply postulate full or empty bands of electronic states, but there are substances such as transition metal oxides which can be either, and it must be the Coulomb interactions between electrons which are decisive. A new entry of physics into technology is provided by a particular example — the chalcogenide glasses where apparently there is a phase change between metallic and insulator forms offering an entirely new sensitive switching device. The wave functions of electrons in semiconductor glasses present a major problem both in technology and in theoretical physics, and Sir Nevill obviously relished the direction of an experimental programme beyond the reach of awkward theorists!

Problems of transitions also occupied D. Sette. Fresh from the "Critical Phenomena" conference in Capri, he reported on a subject which has been the target of many physicists who have come in lately to be "in at the kill" of the subject, only to find nature fighting back in great style. Having a model in the Onsager solution of the two-dimensional Ising model, and, lately, extremely accurate experimental results, physicists have guessed the forms of thermodynamic and correlation functions near critical points. But, in default of complete solutions, attempts have been made to tie down the guesses further by using hypotheses of "scaling" (i.e. assuming that arbitrary sub-divisions of a body for the purpose of calculation will not affect the final answer), and this has now been extended to dynamical problems. It has the aspect of an exciting race, with, as the great prize, the prospect of becoming the conqueror of one of the last fundamental problems left outside high energy physics and astronomy.

A. Rahman, who spoke on the use of computers in physics, must stand

in danger of losing his life, since his message was that large numbers of physicists are redundant. He claimed problems could be solved by computer, and ably defended his claim by offering curves of extremely accurate correlation functions in dense gases. An accuracy is achieved by which the choice of interatomic forces can clearly be checked against experiment. Here indeed is a brave new world, as was seen by the stricken look on many faces after a brilliant exposition.

The world of real solids was reviewed by J. Friedel in his talk on the mechanical properties of solids. Here too the future seems to belong to the computer or rather to those physicists who are prepared to do really full and accurate investigations, for the happy days of considering the ways that faults can occur in lattices and estimating energies by mixing lattice ideas with classical elasticity theory, are over. He reviewed the great qualitative successes of the past in explaining plastic behaviour and showed how much more precise information about electron structure is now needed, and how subtle the precise way in which dislocations act really is. The behaviour of dislocations depends very much on the crystal class, and several unsettled questions on dislocation splitting were brought up. The impression here was of a subject in a very active state, changing from giving general solutions, to really accurate and intricate predictions.

One of the great successes of physics in the last decade or so has been the elucidation of macroscopic quantum phenomena, where there has been a transition from mystery to (in the case of superconductivity) a booming technological industry. W. F. Vinen reviewed the new developments in the field and demonstrated how the physicists in this subject are dealing with the extra subtleties shown by its critical phenomena. The critical fluctuations of superconductors and of liquid helium are related with long range order fluctuations and produce quite new phenomena which are spe-

cially challenging when, as in surfaces, there are geometric factors making the fluctuations even more pronounced. It appears that a new area of great importance has come into being here.

A major tool in post-war physics has been the neutron beam. In addition to the kind of problems studied by X rays, neutrons have the new properties of being magnetically scattered, and, through their inelastic scattering, of yielding information about motion in crystals and liquids. W. Marshall reviewed recent advances in neutron techniques paying special attention to magnetic salts where an enormous amount of information about ionic and covalent bonding is available. Critical phenomena in magnetic systems have received much attention lately and neutrons provide firm information on the time dependence of correlation functions in the critical region. An important point is that the beautiful results described by Marshall require finance of the same order as high energy physics, and surely should be a matter for European collaboration in the future. Europe has played a full part in these developments in the past, and should not lose its expertise.

G. Chiarotti discussed the optical properties of solids, particularly ionic lattices. There was an interesting parallel with J. Friedel's talk, for, though the kind of defect and the resultant properties are very different, the evolution of the subject is strikingly parallel. Chiarotti outlined the powerful array of experimental methods producing information, and showed that the simple models initially proposed for, say, colour centres, now have to be supplemented by the full range of calculations open to the theorist. These have been employed so far only in systems such as semiconductors.

It is often said today that physicists must all be very narrow specialists. This seemed far from the truth in this section of the Florence Conference, for in all the lectures there were references to work in other lectures, and to other parts of the study of con-

densed matter not represented at the Conference. Clearly to know one part of this field really well one must know it all quite well. And, judging from the large and lively audiences, there are many people in Europe who aspire to just that.

Atomic, Molecular and Plasma Physics

The sessions devoted to atomic, molecular, and plasma physics proved that atomic and molecular physics on one hand and plasma physics on the other have little more connection than any two other arbitrarily chosen branches of physics. Historically, there are, of course, common roots. When Langmuir first used the word plasma in a description of gaseous discharges, the latter were still important tools for the study of properties of atoms and, to some extent, of molecules. Naturally, at that time, a classification of the subjects of physics into broad categories would group gas discharges together with atoms and molecules. However, present-day developments in plasma physics are more likely to attract the attention of physicists working on statistical mechanics, fluid dynamics, electrons in solids, or astrophysics, than of workers in atomic and molecular physics. The programme of the Conference also revealed, I believe, other symptoms, such as the choice of subjects for the key-note speeches on the opening day, of a tendency in the EPS to look back to the past.

The lectures on experimental aspects of atomic and molecular collisions and on theoretical aspects of atomic collision problems, by W. Paul and M. J. Seaton, respectively, were squeezed into the time otherwise reserved for one lecture. The theoretical paper dealt with elastic and inelastic collisions of electrons with atoms and positive ions, a subject for which interest is stimulated by astrophysics, upper-atmosphere physics and gas-discharge physics. On the experimental side, more detailed data are becoming available from work with highly resolved beams of atoms, molecules,

ions and electrons, and with sensitive detectors. This work is approaching the resolution of experiments in nuclear physics.

For plasma physicists, on the other hand, there was a choice of lectures on recent developments in their field and they also encountered interesting applications in several lectures on astrophysical subjects.

Most recent developments in plasma physics have been stimulated by the search for a plasma confinement system satisfying the requirements for a fusion reactor. (Of course, thermonuclear reactions attractive for energy production in earthly machines are really stripping reactions, but since stripping does not rhyme so well with fission, the popular press preferred fusion).

First, it became clear that thermonuclear plasmas should be hydro-magnetically stable. The theory of magneto-hydrodynamic stability may be regarded as an extension of hydrodynamic theory, although the former is largely restricted to magneto-hydrostatic stability while the latter is mainly concerned with truly dynamic problems. In its restricted sense, MHD stability is now fairly well understood, although surprises still occur occasionally when the theory has to be applied to realistic situations rather than to idealised plasmas in simple geometries.

Since the mean free paths of particles in thermonuclear plasmas much exceed the dimensions of conceivable reactors, the fluid description is not always appropriate. In fact, some proposed confinement schemes, notably the mirror machines, rely on the plasma behaving not as a fluid, but as a collection of non-colliding particles. Although a modified fluid description is capable of handling many aspects of collisionless plasmas, it fails to cover some for which only statistical mechanics, more specifically the Liouville-Boltzmann-Vlasov equation, is adequate.

The prime example of a phenomenon not described by MHD theories is

Landau damping of electrostatic waves in collisionless plasmas. In this process, a spatial electrostatic wave in an initially Maxwellian plasma vanishes, leaving only a distortion of the velocity distribution. Conversely, it has been found that all sorts of deviation from the Maxwellian velocity distribution, whether connected with production, heating, or localization of the plasma, may give rise to stimulated emission of waves that cause enhanced diffusion of particles across the confining magnetic field.

Much of current thermonuclear research deals with the question of the extent to which such micro-instabilities are responsible for observed anomalous plasma losses, and can be suppressed by known stabilization mechanisms such as magnetic shear and minimum-B confinement. Linearized theory is already well developed and much attention is being paid to non-linear aspects such as saturation of wave amplitude and wave-wave interaction. Also, collisionless shock waves are being actively investigated.

The state of fusion research was reviewed by R.S. Pease; plasma instabilities, by R. Pellat; interplanetary and magnetospheric plasma, by H. Schindler; use of laser light for investigation of atoms, molecules, and plasmas, by H. Zwicker. Thus a balanced picture emerged of some of the most striking experimental and theoretical methods of plasma physics, of encouraging progress towards the thermonuclear goal, and of cross-fertilization with other disciplines.

Quantum Electronics and Optics

G. Toraldo di Francia covered the many fields of modern optics where recent progress has been made (intensity interferometry, laser physics, optical pumping, information theory, etc.) concentrating on the problem of information content in optical images. In this field, the quantum nature of light can be neglected (it comes in only if one is interested in the absolute phase of light vibration, and its measurement is possible only if a

great number of photons is available per cell of phase space).

In the transmission of information by a light beam, there are paradoxes :

— The formation of an image of a two-dimensional object in coherent illumination can be described as a double Fourier transformation in two dimensions, but holography seems to give information on three-dimensional objects, the image through the plate being seen as an object in three dimensions, though the real object is a two-dimensional plate and the light wave carries only information on a two-dimensional object.

— The number of degrees of freedom of an optical image is limited and determined by the spectral width of the spatial frequencies transmitted by the instrument (by the pupil aperture). But many different objects can give the same image, and the final interpretation is based on assumptions concerning the object. Several authors have shown that this conclusion is mathematically wrong : since the Fourier transform is an analytical function, no loss of information should occur and there should be no ambiguity in interpreting the image. Toraldo showed that, in practice, the limitation occurs because the measurement of the light intensity distribution in the image has to be made with tremendous precision. In fact, an important improvement in these measurements would give only a very small gain in information content.

The study of the statistical properties of optical light fields produced by non-thermal equilibrium sources, which followed the development of lasers, has generated intense theoretical and experimental activity in the whole field of optical coherence. E.R. Pike gave a theoretical and experimental analysis of the detection processes of light fields. The theoretical scheme is the interaction of photons with the electrons bound to the atomic system building up the detector. The correlation functions of the field and the photon counting distribution function appear to be the principal tools of the theory.

Thermal light fields, studied with first-order perturbation theory, have a Gaussian character. But the statistical properties of a laser field are different and can be described by the Fokker-Planck equation ; the counting distribution is then of Poisson-type.

H. Zwicker showed that one of the most powerful uses of laser light is its application to the study of light scattering by plasmas. In a gaseous plasma the intensity of the Rayleigh scattering of the neutral atoms and molecules is negligible compared to the intensity of the Thomson scattering by the plasma electrons. The analysis of the spectral distribution of the scattered light for different scattering angles gives detailed information on the velocity distribution, and thus on the temperature, of both the electrons and the ions. The analysis of the scattering spectrum can give also the electron density.

For low electron densities, the scattering is essentially free-electron scattering and the electron temperature can be deduced from the Doppler-broadening of the scattered light. For high electron densities, the scattering is strongly influenced by the correlation between the motions of the electrons and of the ions, giving information on the ion temperature.

R.V. Khokhlov covered the non-linear optics of ultrashort pulses. Optical pulses in the picosecond and subpicosecond range are now available from mode-locked lasers and extremely high power can be reached by subsequent amplification. These two features give special characteristics to non-linear optical interactions. First, ultrashort pulses make it possible to study the behaviour of matter in extremely high fields (the breakdown threshold increases when the pulse duration is decreased). Second, wave interactions may exhibit a transient behaviour, which might come from the finite time of the local non-linear response or the build-up of the wave interaction in space. The response time of the non-linearity can vary widely from seconds (for thermal self-

focusing) down to 10^{-15} seconds for electronic harmonic generation. When the pulse duration is less than the response time the interaction cannot be complete.

A second type of non-linear phenomena is due to the group velocity difference of wave components. In this case, specific effects arise because the interacting light pulses separate during the propagation.

Depending on their relaxation times, stimulated scattering processes of the Raman type have different behaviour under short pulse excitation. Because of their long relaxation times, stimulated Brillouin scattering and stimulated scattering due to entropy fluctuations (central Rayleigh component) are strongly quenched and also the threshold for self focusing is increased when the relaxation time of molecular orientation is longer than the pulse duration. Under these circumstances, stimulated Raman scattering may be studied alone under clean experimental conditions. Transient effects associated with the short duration of the pulses are often observable. The interaction length between pulses at different frequencies is often limited by the different group velocities. In stimulated Raman scattering, amplification is possible in all directions, but the interaction length is larger in the forward direction, where pulses at the laser and Raman frequencies have the same directions of propagation, than in the backward where they have opposite directions.

Second harmonic generation and parametric amplification are also affected by propagation effects. The efficiency of second harmonic generation will depend on the relative group velocities of the fundamental and harmonic pulses. For a Nd^{3+} laser these velocities are much closer in KPD than in LiNbO_3 . In this latter crystal the harmonic wave lags behind the fundamental pulse and produces a broadening in time of the harmonic pulse and a reduction of the conversion efficiency. On the contrary, parametric amplification can lead to a narrowing of the pulse.