Resource Letter CR-1 on Cosmic Rays

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This is one of a series of Resource Letters on different topics, intended to guide college physicists to some of the literature and other teaching aids that may help them improve course contents in specified fields of physics. No Resource Letter is meant to be exhaustive and complete; in time there may be more than one letter in some of the main subjects of interest. Comments and suggestions concerning the content and arrangement of letters as well as suggestions for future topics will be welcomed. Such communications should be sent to Professor Joel Gordon, Chairman, Resource Letter Committee, Department of Physics, Amherst College, Amherst, Massachusetts.

Notation: The letter *E* after an item number indicates *elementary* level, useful principally for freshman liberal arts through sophomore physics courses; the letter *I* indicates *intermediate* (junior, senior) level; and the letter *A* indicates *advanced* material principally suited for senior, graduate study. An asterisk (*) indicates items particularly recommended for introductory study.

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IN 1912, as the result of measurements in the high atmosphere, Victor Hess put forward the hypothesis that there existed a penetrating radiation originating outside the terrestrial atmosphere. For approximately fifty years after this beginning, the field of cosmic-ray physics followed a more or less well-defined path in exploiting that original discovery. Now it may well be that the uniqueness of cosmic rays as an area of physics has come to an end, and the interests of workers traditionally in the field have been absorbed in many diverse but related areas.

Two main streams of interest existed side by side during this period. The first is the study of the elementary particles and the interaction of these particles at high energies. Many of the transitory or unstable elementary particles were in fact discovered by cosmic-ray physicists in the period from 1929 to 1958, using their traditional tools of investigation such as magnets, cloud chambers, and nuclear emulsions, supplemented by complex arrays of electronic counting devices. But the artificial production of π mesons by the Berkeley cyclotron in 1948 (near the time of the CalTech Cosmic Ray Symposium) marked the beginning of a change. By 1955 or 1956 cosmic rays could no longer compete with accelerators for elementary particle studies in energy ranges below 3×10^{10} eV. Many groups who were traditionally cosmic-ray physicists had by then been absorbed in large machine facilities in the area now properly designated as high-energy nuclear physics.

There remained, however, a considerable interest in cosmic-ray particles and interactions at energies up to the highest known values, about 10^{19} eV, not only for studies of nuclear cascades and extensive showers in the atmosphere, but for investigating by these means the origin of primary particles at these ultrahigh energies.

The nature and origin of the primary particles has constituted the second traditional area of interest in cosmic-ray physics. The year 1948 also marked one of the milestones in this area, as the application of cloud chamber, nuclear emulsions, and other devices to high-altitude measurements permitted direct identification of the primaries for the first time. Studies of the primary particles rapidly became of importance for astrophysics, and many cosmic-ray physi-

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cists made contributions directly in the field of astronomy. This part of the subject continues as one of the central areas. Experience with the techniques of particle physics had led cosmic-ray groups also into the fields of x-ray, γ-ray, and neutrino astronomy.

Since the International Geophysical Year period much interest has developed in the sun as a generator and modulator of cosmic rays, and in the earth and its magnetosphere. The opportunity to use solar and galactic cosmic rays as tools for exploring the solar system has been well utilized, and the discovery of the region of trapped particles near the earth has been exploited by cosmic-ray research groups everywhere.

Cosmic-ray particles produce rare isotopes in meteorites and in the atmosphere, and a sizeable effort now exists in studies of these phenomena in geochronology and the origin of the solar system.

A single resource letter cannot cover all of the widespread interests in the field of cosmic rays, if in fact the field as an entity even exists! We have, therefore, restricted this letter to the following:

I. A selected list of original papers which represent milestones in the field of cosmic rays during the first fifty years of its history.

II. A list of review articles, as recent as possible, covering various areas of interest.

III. A brief list of published recent cosmic-ray symposia.

IV. Books on cosmic rays or related subjects normally used by workers in the field.

V. A. Popular books and articles. B. Chapters in physics text books. C. Educational films on cosmic rays or related subjects.

The listing cannot possibly be complete or exhaustive. It is our hope that the nonspecialist will simply find this an adequate entree to a few important aspects of an enormous field. He might then become interested in pursuing a more detailed inquiry in more specialized areas such as ultrahigh energy interactions and extensive air showers; the sun and cosmic rays; the earth's magnetosphere; astrophysical problems touching on the origin of cosmic rays, etc.

I. ORIGINAL PAPERS REPRESENTING MILESTONES IN COSMIC-RAY RESEARCH

1.E **"Über Beobachtungen der Durchdringenden Strahlung bei Sieben Freiballonfahrten."** V. F. Hess. Physik. Z. **13**, 1084 (1912). This paper describes the results of the manned balloon flights which "discovered" cosmic rays. Flights beginning in April 1912 indicated that above about 1000 meters the ionization intensity in an electrometer began to increase so that at about 4000 meters the intensity was twice that on the ground. This proved that the rays were not coming from the ground. Hess measured an exponential absorption of the rays in the atmosphere and postulated that they were coming from outside the atmosphere, and probably not entirely from the sun since no diurnal variation was observed.

2.E **"Messungen der Durchdringenden Strahlung im Freiballon in Gröseren Höhen."** W. Kolhörster. Physik. Z. **14**, 1153 (1913). A description of three balloon flights in the summer of 1913. One of the flights ascended over 6000 meters while measuring cosmic ray ionization by an electrometer.

3.E **"Penetrating Radiation."** J. Clay. Proc. Acad. Sci. Amsterdam **30, 1115** (1927). During ocean trips between Java and Holland, a consistently lower cosmic-ray ionization intensity was found near the equator. This was the first evidence that cosmic rays consisted in part, at least, of charged particles.

4.E **"High Frequency Rays of Cosmic Origin."** R. A. Millikan and G. H. Cameron. Phys. Rev. **28**, 851 (1926). An electrometer, lowered into lakes at different altitudes, showed that the intervening layer of air between the two lake levels acted only as an absorber of radiation and not a source. It was thus concluded that the great penetrating power of the radiation was real and that the rays were indeed of cosmic origin. Millikan and Cameron had, a year earlier, given the rays their present name: cosmic rays.

5.E **"Elektronenzählrohr zur Messung Schwächster Aktivitäten."** H. Geiger and W. Müller. Naturwiss. **16**, 617 (1928). A letter describing new apparatus for detecting weak radioactivity. This instrument is still in wide use today and is known as the Geiger–Müller counter.

6.A **"Über die Streuung von Strahlung durch freie Elektronen nach der Neuen Relativistischen Quantendynamik von Dirac."** O. Klein and Y. Nishina. Z. Physik **52**, 853 (1929). The relativistic treatment of the Compton scattering process using the Dirac wave equation.

7.I **"Über eine Neue Art sehr Schneller β-Strahlen."** D. Skobeltzyn. Z. Physik **54**, 686 (1929). This paper reports the first observations of cosmic rays using a Wilson cloud chamber. The chamber was equipped with a magnetic field and stereoscopic photography, and showed penetrating tracks with little curvature. These were identified as the secondaries of "höhenstrahlung" in the atmosphere. The work was carried out at the Polytechnical Institute of Leningrad in February 1929.

8.I **"Das Wesen der Höhenstrahlung."** W. BOTHE AND W. KOHLHÖRSTER. Z. Physik **56**, 751 (1929). The authors showed that cosmic rays near the ground consisted of high-speed charged particles by using a double counter experiment with absorbing material between. This is the first use of Geiger counters in coincidence, to discriminate charged particles from photons.

9.I **"Method of Registering Multiple Simultaneous Impulses of Several Geiger Counters."** B. ROSSI. Nature **125**, 636 (1930). The famous Rossi circuit is described. This circuit permits the registering of threefold or higher coincidences for studying the paths of cosmic-ray particles. The circuit represents a considerable improvement over the unsymmetrical arrangement formerly employed by Bothe.

10.A **"A New Theory of Magnetic Storms."** S. CHAPMAN AND V. C. A. FERRARO. Terrest. Magnetism and Atmospheric Elec. **36**, 77, 171 (1931). This is the basis of the present-day theory of magnetic storms wherein a solar corpuscular stream (plasma) from a solar flare or active region interacts with the earth's magnetic field one to two days after leaving the sun.

11.A **"A Theory of Electrons and Protons" and "Quantized Singularities in the Electromagnetic Field."** P. A. M. DIRAC. Proc. Roy. Soc. (London) **A126**, 360 (1930) and **A133**, 60 (1931). The first paper discusses the negative energy states predicted by the relativistic quantum theory. The "hole" of positive charge was at first tentatively identified with a proton.

In the second paper the ideas of Oppenheimer and others are discussed and the "anti-electron" emerges as the only possible interpretation of the holes in the negative energy regions. It is pointed out that in vacuum the anti-electron would be stable, but would annihilate in matter and could not normally be observed. The creation of "anti-electrons" by hard γ rays of at least $\frac{1}{2}$ MeV is predicted.

This second paper also states that the existence of magnetic monopoles is not precluded by quantum mechanics.

12.I **"Messung der Ultrastrahlung in der Stratosphäre."** E. REGENER. Naturwiss. **20**, 695 (1932). An account of the first very high-altitude measurements of cosmic rays. A self-recording electrometer is sent up to 28 km by a balloon. Cosmic-ray ionization versus pressure curves to 25 mm Hg are in agreement with Kolhröster's earlier measurements up to 230 mm Hg. Extrapolation of the data to 0 pressure reveals an ionization of 275 ion pairs per cubic centimeter per second. Other new findings include the bending over of the ionization vs pressure curve above 150 mm Hg (12 km) and a relatively slower increase in ionization the rest of the way up.

13.I **"A Geographic Study of Cosmic Rays."** A. H. COMPTON. Phys. Rev. **43**, 387 (1933). Eight different expeditions at 69 stations distributed over the globe made measurements of the cosmic radiation using a high-precision ionization chamber. The results conclusively showed a systematic increase in ionization with increasing latitude. The increase was greater at high altitude than at sea level. Comparisons were made with the theory of Lemaitre and Vallarta (see reference 14), and the author concludes that most of the primaries consist of charged particles (electrons) with energies up to 10^{10} eV.

14.A **"On Compton's Latitude Effect of Cosmic Radiation."** G. E. LEMAITRE AND M. S. VALLARTA. Phys. Rev. **43**, 87 (1933). Lemaitre and Vallarta show how to apply Störmer's theory (see reference 18) of the aurora to cosmic-ray trajectories. The theoretical results for the allowed energies are compared with A. H. Compton's extensive latitude surveys. Particles of 0.5 to 3.0 BeV energy must be present as primaries. A mixture of particles, including neutral radiation, is not excluded by this study.

15.I **"The Variation of Cosmic Ray Intensities with Azimuth on Mt. Washington, N. H."** (abstract). T. H. JOHNSON. Phys. Rev. **43**, 381 (1933). **"The Azimuthal Asymmetry of the Cosmic Radiation."** T. H. JOHNSON. Phys. Rev. **43**, 834 (1933). The discovery of the east–west effect in the cosmic radiation. This effect indicated that the primary radiation was composed predominantly of positively charged particles.

16.I **"The Positive Electron."** C. D. ANDERSON. Phys. Rev. **143**, 491 (1933). Positive evidence is presented for the positron in the form of cloud chamber photos with a magnetic field and a lead plate. It is shown that the curved tracks which penetrate the lead arise from particles of protonic charge but of mass close to that of the electron. These positrons are identified as coming from nuclei in the lead, as they are accompanied by other tracks.

*17.I **"Some Photographs of the Tracks of Penetrating Radiation."** P. M. S. BLACKETT AND G. OCCHIALINI. Proc. Roy. Soc. **A139**, 699 (1933). This paper describes the invention of the counter-controlled Wilson cloud chamber. With this device 80% of the photographs contained cosmic-ray tracks. The authors found showers of particles some of which were positive and of mass similar to the electron. The authors conclude that they are observing showers of positive and negative electrons which are born and disappear according to the Dirac theory. Discussions held with Dirac are reported, including a cross-section calculation applicable to the annihilation process. Many excellent plates of the photographs are given.

18.A **"Critical Remarks on a Paper by G. Lemaitre and M. S. Vallarta on Cosmic Radiation."** C. STÖRMER. Phys. Rev. **45**, 835 (1934). In this paper Störmer makes a bitter attack on the use by Lemaitre and Vallarta of Liouville's theorem to simplify enormously the application of Störmer's theory to cosmic-ray problems. One finds here the references to Störmer's original work, and an interesting brief discussion of the mathematics of charged particle orbits in a magnetic dipole field. The reader may also be led to read the reply to the above by Lemaitre and Vallarta, and remarks by Swann in later issues of the *Physical Review.* (See item 74.)

19.A **"On the Stopping of Fast Particles and on the Creation of Positive Electrons."** H. BETHE AND W. HEITLER. Proc. Roy. Soc. **A146**, 83 (1934). In this fundamental paper processes of the radiation of electromagnetic energy by an electron in the field of a nucleus and the inverse process, namely the creation of a positive–negative pair by a light quantum in the field of a nucleus, are treated by Born's method.

The effects of screening are taken into account. Straggling of electrons due to energy loss by collision and radiation is calculated. Cross sections and energy distribution are presented.

20.A **"On the Interaction of Elementary Particles."** H. YUKAWA. Proc. Physico-Math Soc. Japan **17**, 48 (1935). The famous paper describing a new theory of nuclear exchange forces. Yukawa postulates that a transition from a proton to a neutron state and vice versa takes place through the exchange of a charged particle with a mass of about 200 electron masses. This proposed particle, first identified incorrectly with the "μ" meson, is now known to correspond to the "π" meson. In his summary, Yukawa also suggested that his "massive quanta," as he called them, may have some bearing on cosmic-ray showers.

21.I **"Dreifachkoinzidenzen der Ultrastrahlung aus vertikaler Richtung in der Stratosphare."** G. PFOTZER. Z. Physik **102**, 23 (1936). A triple coincidence counter arrangement was flown to 10 mm Hg residual pressure (29 km) on a balloon. A maximum in the vertical counting rate was observed at about 80 mm Hg. This well-known maximum in the secondary cosmic-ray intensity now bears the title "the Pfotzer maximum."

22.A **"On Multiplicative Showers."** J. F. CARLSON AND J. R. OPPENHEIMER. Phys. Rev. **51**, 220 (1937). Quantum theory is applied to the process of pair production and radiation. The analytic solution of the diffusion equation is carried through to find the distribution of electrons and gamma rays as a function of their energy, the primary energy, and the thickness and atomic number of matter traversed.

23.I **"New Evidence for the Existence of a Particle of Mass Intermediate between the Proton and Electron."** J. C. STREET AND E. C. STEVENSON. Phys. Rev. **52**, 1003 (1937). With the aid of a counter-controlled magnetic cloud chamber, Street and Stevenson captured a particle which by its ionization count, track curvature in the magnetic field, and range could be identified as a particle of 130 times the electron mass. It is now known as the μ meson.

24.I **"Cosmic Ray Particles of Intermediate Mass."** C. ANDERSON AND S. H. NEDDERMEYER. Phys. Rev. **54**, 88 (1937). A single magnetic cloud chamber photo shows a particle which penetrates a lead plate and comes to rest in the gas of the chamber. By range, momentum, momentum loss, and ionization it is shown that the mass of the particle is intermediate between that of a proton and electron.

25.I **"Les Grandes Gerbes de Rayons Cosmiques."** P. AUGER. J. Phys. Radium **10**, 39 (1939). Experiments on the Pic du Midi and the Jungfraujoch, as well as in Paris, show that one can obtain coincidences between Geiger counters separated horizontally by many meters. Auger showed that these were not spurious, but were caused by large showers of electrons produced simultaneously in an atmospheric cascade. The absorption of the particles was investigated and Wilson chamber photos were made of particle tracks. The theory of Bhaba–Heitler was applied to show the presence of energies up to 10^{14} eV.

26.A **"The Transition Curve for Showers in Lead."** in University of Chicago Symposium, June 1939. B. ROSSI AND L. JANOSSY. Rev. Mod. Phys. **11**, 279 (1939). Observations, conducted at the University of Manchester, on the *transition curves* for showers produced by photons in blocks of lead. The observed maximum in number of particles and decrease with greater amounts of lead agrees with the predictions of cascade shower theory.

27.I **"The Variation of the Hard Component of Cosmic Rays with Height and the Disintegration of Mesotrons."** B. ROSSI, N. HILBERRY, AND J. B. HOAG. Phys. Rev. **57**, 461 (1940). The vertical intensity of the hard component of cosmic rays is measured at various altitudes (Chicago, Denver, Echo Lake, and Mount Evans) with a threefold coincidence counter tube arrangement. Intensity differences after passing through equivalent masses of air and carbon were correctly interpreted as being due to mesotron decay, supporting the previous hypothesis of the instability of mesotrons. These experiments provided a test of the special theory of relativity by showing that the radioactive decay mean life was greatly increased for the moving mesons, in agreement with Einstein's theory.

28.I **"Evidence for the Transformation of Mesotrons into Electrons."** E. J. WILLIAMS AND G. E. ROBERTS. Nature **145**, 102 (1940). The authors show the first cloud chamber photo obtained of the decay of a positive cosmic-ray meson in the gas of the chamber. The photo shows the dense track of the stopping meson and the lightly ionizing trail of a positive electron leaving the end. The event is compared with Yukawa's theory. (This was actually a μ^{+}.)

29.I **"Observations on the Tracks of Slow Mesons in Photographic Emulsions."** C. M. G. LATTES, G. P. S. OCCHIALINI, AND C. F. POWELL. Nature **160**, 453 (1947). Plates were exposed at Chacaltaya in the Bolivian Andes at heights of 5500 meters, and at the Pic du Midi. Forty examples were found in the emulsions of secondary mesons produced by charged mesons brought to rest. It was possible to measure the *relative* masses accurately as the *relative* grain density was known accurately. Fading and developing effects did not affect the relative value. Thus, the authors demonstrated the existence of a meson, heavier than the μ meson, which produced the μ by decay, and is now known as the "π" meson.

30.I **"Evidence for the Existence of New Unstable Elementary Particles."** G. D. ROCHESTER, AND C. C. BUTLER. Nature **160**, 855 (1947). Rochester and Butler describe their discovery of the V particle, and give examples of cloud chamber photos in which a forked track appears below a lead plate in which a high energy interaction has occurred. They interpret the event as the spontaneous decay of a neutral particle, whose decay depends on the distance traveled and not the amount of matter. Its mass is more than 980 electron masses, and it is now recognized as a member of the K-meson group.

*31.I **"The Heavy Component of Primary Cosmic Rays."** P. FREIER, E. J. LOFGREN, E. P. NEY, AND F. OPPENHEIMER. Phys. Rev. **74**, 1818 (1948). **"Investigation of the Primary Cosmic Radiation with Nuclear Emulsions."** H. L. BRADT AND B. PETERS. Phys. Rev. **74**, 1828 (1948). These two papers describe the discovery of the heavy primary cosmic rays in a high-altitude balloon flight carrying a Wilson cloud chamber and nuclear emulsions in 1948. The articles contain photos of the emulsion tracks and cloud chamber photos of the heavies and their interactions. The flux of heavies is derived and collisions between heavy primaries and emulsion nuclei are studied.

32.I **"The Mass of the Mesotron."** R. B. BRODE. Rev. Mod. Phys. **21**, 37 (1949). The charge of the mesotron is found, from the "minimum" ionization rate compared to electrons, to be within 2% of the electronic charge. The method of momentum (by magnetic curvature in a cloud chamber) and range (by lead plates also in a cloud chamber) is applied to determine the mass of single cosmic-ray particles whose tracks were observed. 78 determinations give a value of 215 ± 2 times the electronic mass (π meson).

*33.I **"On the Origin of Cosmic Radiation."** E. FERMI. Phys. Rev. **75**, 1169 (1949). The pioneer paper on the acceleration of cosmic rays in galactic space by collisions against moving magnetic fields. **"Galactic Magnetic Fields and the Origin of Cosmic Radiation."** E. FERMI. Astron. J. **119**, 1 (1954). A further discussion of the first paper, proposing a modified mechanism and considering the problem of injecting heavy nuclei. The "Fermi mechanism" remains one of the most probable processes for the production of high energy particles in nature. These ideas have had great influence on many writers concerned with the origin of cosmic rays.

34.I **"The Extraordinary Increase of Cosmic Ray Intensity on November 19, 1949."** S. E. FORBUSH, T. B. STINCHCOMB, AND M. SCHEIN. Phys. Rev. **79**, 501 (1950). Describes the world-wide increase of intensity on 19 November 1949 as well as three other previous increases observed on the *ground* due to a solar eruption. An example of cosmic rays produced in our solar system, and the first records of cosmic rays produced in solar flares.

35.I **"Kometenschweife und Solare Korpuskular Strahlung."** L. BIERMANN. Z. Astrophys. **29**, 274 (1951). From the observed motions of comet tails, Biermann suggested the presence of a corpuscular solar stream having a radial velocity of from 500–1500 km/sec. This radiation is now known as the solar wind.

36.A **"The Origin of Cosmic Rays."** V. L. GINZBURG. Dokl. Akad. Nauk SSSR **92**, 1133 (1953). A supernovae origin of cosmic rays is presented, based on empirical data from observations of cosmic radio emission.

37.A **"Solar Cosmic Rays of February, 1956 and their Propagation through Interplanetary Space."** P. MEYER, E. N. PARKER, AND J. A. SIMPSON. Phys. Rev. **104**, 768 (1956). Observations (by a chain of six neutron monitors and balloon equipment) of cosmic rays from the great flare of 23 February 1956 are described. A model is proposed for the magnetic configuration of the inner solar system, based on the diffusion of the solar cosmic rays. The flare particles are used as probes to study the mechanism for a "Forbush decrease" in progress at the time.

38.I **"Cosmic Radiation Neutron Intensity Monitor."** J. A. SIMPSON, Ann. Intern. Geophys. Yr. **4**, 351 (1957). A description of the design and operation of large neutron monitors of the type employed during the International Geophysical Year. Included are descriptions of pile construction, proportional counters, electronic circuitry, data recording, and operation and maintenance schedules. Methods of correcting data to standard atmospheric pressure are included.

39.A **"The Low Energy End of the Cosmic Ray Spectrum of Alpha-Particles."** P. H. FOWLER, C. J. WADDINGTON, P. S. FREIER, J. NAUGLE, AND E. P. NEY. Phil. Mag. **2**, 157 (1957). One of the first direct determinations of the low-energy (130–750 meV/nucleon) primary alpha particle differential energy spectrum. Photographic emulsions were flown from Saskatoon, Canada, to make the measurements.

40.A **"Dynamics of the Interplanetary Gas and Magnetic Fields."** E. N. PARKER. Astrophys. J. **128**, 664 (1958). The mathematical development of the solar coronal expansion predicting the solar wind. Experimental observations by Lunik II confirmed this in September 1959.

41.I **"Some Preliminary Reports of Experiments in Satellites 1958 Alpha and Gamma."** J. A. VAN ALLEN, G. H. LUDWIG, E. C. RAY, AND C. E. MCILWAIN. Trans. Am. Geophys. Union **39**, 767 (1958). National Academy of Science, Washington, D. C., IGY Satellite Rept. Sec. 3, 73–92 (1958). The first published accounts of the discovery of trapped radiation zones around the earth.

42.I **"Radiation Observations with Satellite 1958 ε."** J. A. VAN ALLEN, C. E. MCILWAIN, AND G. H. LUDWIG. J. Geophys. Res. **64**, 271 (1959). This is the first summary of radiation belt measurements by the United States satellites published by their discoverer in a regular journal. This paper indexes earlier accounts and describes measurements by Explorer IV of the "inner" radiation belts and the lower fringes of the "outer" region.

43.I **"Balloon Observations of Solar Cosmic Rays on March 26, 1958."** P. S. FREIER, E. P. NEY, AND J. R. WINCKLER. J. Geophys. Res. **64**, 685 (1959). Photographic emulsions flown on high-altitude balloons at Minneapolis following a solar flare revealed that the solar cosmic rays produced in the flare were protons. Another interesting observation was that protons having a rigidity well below the theoretical geomagnetic (Störmer) cutoff rigidity at this latitude were present.

44.I **"A Study of the Interplanetary Ionized Gas, High Energy Electrons, and Corpuscular Radiation from the Sun by Means of the Three-Electrode Trap for Charged Particles on the Second Soviet Cosmic Rocket."** K. I. GRINGAUZ, V. V. BEZROKIKH, V. D. OZEROV, AND R. E. RYBCHINSKII. Dokl. Akad. Nauk SSSR **131**, 1301 (1960) [English transl.: Soviet Phys.–Doklady **5**, 361 (1960)]. The second Soviet moon rocket, Lunik II, launched on 12 September 1959, detected an intensity of positive ions (assumed to be protons) of about 2×10^8 $cm^{-2}\cdot sec^{-1}$ exceeding 15 eV in energy outside the magnetic field of the earth. These particles were correctly interpreted as corpuscular emission from the sun, and constituted the first experimental verification of the solar wind.

45.I **"Cloud Chamber Observations of Primary Cosmic Ray Electrons."** J. A. EARL. Phys. Rev. Letters **6**, 125 (1961). **"Electrons in the Primary Cosmic Radiation."** P. MEYER AND R. VOGT. Phys. Rev. Letters **6**, 193 (1961). These two papers describe the measurement for the first time of a definite flux of electrons in the primary radiation. The paper of Earl identifies the particles by shower production in lead plates in a cloud chamber; the paper of Meyer and Vogt, by scintillation counter techniques.

46.I **"Extremely Energetic Cosmic Ray Event."** J. LINSLEY, L. SCARSI, AND B. ROSSI. Phys. Rev. Letters **6**, 485 (1961). The authors describe the detection of a primary cosmic-ray particle with an energy of at least 10^{19} eV utilizing a huge (1.8 km in diameter) air shower detector array at the MIT Volcano Ranch station in New Mexico. It is pointed out that with such a high energy, the primary particle almost certainly acquired its energy outside our galaxy.

47.I **"The Topology of the Sun's Magnetic Field and the 22-Year Cycle."** H. W. BABCOCK. Astrophys. J. **133**, 572 (1961). This is a proposed mechanism for the production of the 11- and 22-year cycles of the sun. Written by one of the pioneers in the measurement of surface magnetic fields on the sun, it contains references to important results in solar physics, and a description of the sun's magnetism.

48.I **"Solar Cycle Variation of Cosmic Ray Intensity, Cosmic Ray Activity and Geomagnetic Activity 1937–1961."** S. FORBUSH. Semaine d'Etude sur le Probleme du Rayonnement Cosmique dans l'Espace Interplanetaire. Pontificial Academy, Rome, 1–6 October, 1962. This paper is one of the outstanding long-time records of terrestrial cosmic rays. It discusses the Huancayo, Peru, high-altitude ion chamber in relation to sunspots and geomagnetic activity and is written by the discoverer of the "Forbush decrease" and of solar-flare cosmic rays.

49.A **"On Cosmic Rays as an Extra-Galactic Phenomenon."** G. R. BURBIDGE AND F. HOYLE. Proc. Phys. Soc. **84**, 141 (1964). The relation of cosmic rays to the extragalactic radio sources is discussed. The paper argues that violent events in the nuclei of galaxies will provide a powerful source of intergalactic cosmic rays. The characteristic spectrum may be due to a Fermi process on an extragalactic scale.

II. REVIEW ARTICLES

50.A **Progress in Elementary Particle and Cosmic Ray Physics.** J. G. WILSON AND S. A. WOUTHUYSEN, Eds. (North-Holland Publ. Co., Amsterdam.) (Interscience Publishers, New York, U. S. Distributor.) Eight volumes in this series have been published; principally intended for the research worker. The review articles are written by currently active physicists, usually at advanced mathematical level. The publication dates are as follows: Vol. I, 1952; Vol. II, 1953; Vol. III, 1956; Vol. IV, 1958; Vol. V, 1960; Vol. VI, 1962; Vol. VII, 1963.

51.A **"Cosmic Rays."** B. PETERS. Chapter 12 in *Handbook of Physics*, E. U. CONDON AND HUGH ODISHAW, Eds. (McGraw-Hill Book Co., New York, 1958), 43 pages with bibliography of research papers. A brief history is presented, followed by an outline of the primary particles and an extensive discussion of atmospheric and nuclear processes such as stars, showers, and nucleon–nucleon collisions. A brief discussion of time variations is included.

52.A **"Origin and Dynamics of Cosmic Rays."** E. N. PARKER. Phys. Rev. **109**, 1328 (1958). Discusses acceleration mechanisms which may produce cosmic rays in solar flares or in the galaxy. Where possible, mathematical arguments are used. The author discusses Fermi's mechanisms and their modifications, and the betatron mechanisms, giving much attention to detailed particle motions and hydromagnetic wave phenomena which might produce accelerations.

53.A **"The Composition of the Primary Cosmic Radiation."** C. J. WADDINGTON. *Progress in Nuclear Physics*, O. R. Frisch, Ed. (Pergamon Press, Inc., New York 1960), Vol. 8, pp. 3–45. An extensive survey of the knowledge of the composition of the primary cosmic radiation as of mid-1959. Numerous abundance and flux tables are given. The method of extrapolation of data to the top of the atmosphere is presented along with a table of fragmentation parameters used in the solution of the one-dimensional diffusion equation for heavy nuclei.

*54.E **"Primary Cosmic Rays."** J. R. WINCKLER. Radiation Res. **14**, 521 (1961). Written for non cosmic-ray physicists. Surveys galactic and solar cosmic radiation, describes instrumentation, the interpretation of experiments, and various important discoveries in the field. Included is a list of polar cap cosmic noise absorption events, Type IV radio emission events, and solar cosmic-ray events. The interrelation among these phenomena is discussed.

*55.A **"Extensive Air Showers."** G. COCCONI. *Handbuch der Physik* (Springer-Verlag, Berlin, 1961), Vol. 46–1. Research on the highest energy particles known to man is presented in this review. It describes the electromagnetic cascade in fairly condensed form and compares this with the lateral and vertical dimensions experimentally observed. The paper contains considerable material on the nuclear and mesonic components of cascades, both above and underground. The author discusses energy spectra and time and space variations of primaries producing these energetic events.

56.A **"Theory of Geomagnetic Effects of Cosmic Radiation."** M. S. VALLARTA. *Handbuch der Physik* (Springer-Verlag, Berlin, 1961), Vol. 46–1. One of the pioneers in this field summarizes his work and that of his collaborators. Most of their charts and graphs on the classical allowed and forbidden regions in the terrestrial dipole field (charts which are otherwise scattered throughout the literature) are collected here. An extensive bibliography and mathematical development are presented.

*57.A **"The Origin of Cosmic Rays."** P. MORRISON. *Handbuch der Physik* (Springer-Verlag, Berlin, 1961), Vol. 46–1. One of the best articles in existence on this subject. Discusses the origin of cosmic rays in our own galaxy on the basis of known astrophysical data. The paper summarizes the properties of primary cosmic rays relevant to the question of origin (useful in itself), the interaction of cosmic rays with particles and magnetic fields in the galactic medium, the acceleration and radiation by particles in magnetic fields, and particle diffusion. Solar-flare phenomena, explosive stars, the Crab Nebula, and the galaxy as a whole are discussed. An authoritative discussion of previous ideas and a useful general reference to previous books and reviews (with commentary) increase the value for all readers.

58.A **"Origin, Age and Composition of Meteorites."** E. ANDERS. Space Sci. Rev. **3**, 583 (1964). An extensive review article attempting to bring together and to evaluate all significant evidence on the origin of meteorites. The cosmic-ray exposure age is discussed at length.

*59.I **"Advances in Particles and Fields Research in the Satellite Era."** W. N. HESS, G. D. MEAD, AND M. P. NAKADA. Rev. Geophys. **3**, 521 (1965). An excellent concise and accurate account of the last six years' progress in knowledge of energetic particles in the solar system. It includes discovery of the Van Allen belts, the magnetosphere, the aurora, solar particles and the interplanetary medium. The paper contains a complete bibliography and list of important space experiments, including the artificially generated trapped radiation.

*60.I **"Composition of Solar Cosmic Rays."** S. BISWAS AND C. E. FICHTEL. Space Sci. Rev. 4, 709 (1965). An excellent summary of information concerning energetic proton and heavier components produced by solar flares and observed near the earth. The article, written by two of the principal research workers in the application of nuclear emulsion techniques to this problem, summarizes findings over the solar cycle, 1954–1965. The authors discuss H, H^2, H^3, He^3, He^4, and heavier elements, and problems of production. Contains a very complete index of recent work.

61.A **"Some Problems in Gamma and X-Ray Astronomy."** V. L. GINZBURG AND S. I. SYROVATSKII. Space Sci. Rev. 4, 267 (1965). Devoted exclusively to gamma and x-ray radiation generated by cosmic rays. Possible emission mechanisms are discussed and a theoretical calculation of intensities due to the various mechanisms is compared with observations. Discrete sources of gamma rays are included.

62.A **"Dynamical Theory of the Solar Wind."** E. N. PARKER, Space Sci. Rev. **4**, 666 (1965). Historical development of the solar wind theory and a review of the basic theoretical dynamical properties of the supersonic coronal expansion. Models of the solar corona and coronal filaments are discussed.

*63.A **"The Spectrum and Charge Composition of the Primary Cosmic Radiation."** W. R. WEBBER. *Handbuch der Physik* (Springer-Verlag, Berlin, 1966), Vol. 46–2, Extensive review of the knowledge of the spectrum and charge composition of the primary cosmic radiation as of mid-1964. Includes ground level, balloon, satellite, and space probe observations. Solar modulation influences are discussed as are theories of origin and propagation of the radiation to the earth. An extensive bibliography of work done in the field is given.

64.A **"High Energy Cosmic Gamma Rays."** G. GARMIRE AND W. L. KRAUSHAAR. Space Sci. Rev. **4**, 123 (1965). The authors have summarized the limited knowledge of gamma rays of cosmic origin. Various emission and absorption mechanisms are presented. Intensity estimates and experimental upper limits are given along with a description of the various detection methods.

III. PUBLISHED COSMIC-RAY SYMPOSIA

65.A **Ninth International Conference on Cosmic Rays, London, England, 6-17 September, 1965.** Sponsored by the International Union of Pure and Applied Physics with the Institute of Physics and the Physical Society. These proceedings will be published in two volumes.

66.A **Symposium on Cosmic Rays, California Institute of Technology, June 21–23, 1948.** Rev. Mod. Phys. **21**, 1 (1949). Papers in this symposium include atmospheric showers, many results concerning mesons and nuclear interaction at high energy, the newly discovered heavy nuclei in the primaries, and solar cosmic rays. Contains R. A. Millikan's last paper on the atom-annihilation theory. Given, but not published, was a paper by C. M. G. Lattes on π mesons artificially produced at Berkeley. Contributions were made by Brode, Rochester, Heitler, Rossi, Oppenheimer, Bradt, Peters, Freier, Ney, Lofgren, and many others.

67.A **Semaine d'Etude sur le Probleme du Rayonnement Cosmique dans l'Espace Interplanetaire, Pontifical Academy, Rome, 1–6 October, 1962.** An important conference dealing with the primary radiation and its variations produced by solar effects. The proceedings include solar physics, discussions of solar-produced cosmic rays, satellite plasma, and magnetic field measurements.

68.A **Space Research.** Proceedings of the annual international space science symposia sponsored by COSPAR (Committee on Space Research). Published by North-Holland Publishing Company, Amsterdam, Holland. **Space Research I;** Nice, 11–16 January 1960. **Space Research II;** Florence, 10–14 April 1961. **Space Research III;** Washington, 2–8 May 1962. **Space Research IV;** Warsaw, 4–10 June 1963. **Space Research V;** Florence, 12–16 May 1964. **Space Research VI;** Mar Del Plata, Argentina, May 1965. These extensive compendia (e.g., Vol. V has 1248 pages) contain mainly research papers in the fields of upper atmosphere, solar, planetary and energetic particle physics, as well as satellite technology and astronomy. Of particular interest to cosmic-ray physicists are papers on the Van Allen belts, interplanetary fields and plasma, solar produced cosmic rays, and in general, the exploration of the cosmic-ray particles of lower energy from the sun and the galaxy by means of balloons, rockets, and satellites. Most of the principal workers in this area of cosmic rays have provided papers for these symposia. In the later volumes special attention has been given to rocket and satellite astronomy, particularly the observation of x rays and γ rays (a subject of great current interest to many cosmic-ray physicists).

IV. BOOKS ON COSMIC RAYS OR RELATED SUBJECTS

*69.E **Atlas Typischer Nebelkammerbilder.** W. Gentner, H. Maier-Leibnitz, and W. Bothe. (Springer-Verlag, Berlin, 1940; Edwards Brothers, Inc., Ann Arbor, Michigan, 1944), 125 pp. **An Atlas of Typical Expansion Chamber Photographs.** W. Gentner, H. Maier-Leibnitz, and W. Bothe. (Interscience Publishers, Inc., New York; Pergamon Press, Ltd., London, 1954), 199 pp. The original German edition begins with the theory and description of the Wilson cloud chamber. Included are numerous cloud chamber photos of alpha particles, β rays and γ rays from radioactive sources, and high energy cosmic rays and their interactions in lead plates in the cloud chambers. The edition published in 1954 contains both English and French translations and presents more and better quality pictures than the original edition. Many of the "classics" in cosmic-ray photos may be found here.

70.E **Rayons Cosmiques.** P. Auger. (University of Paris Press, Paris, France, 1941.) This very readable book contains a good historical summary as of 1941, and discusses experiments of Clay, Compton, Rossi, Auger, Millikan, and others. Plates of early cloud chamber photos of showers are given. No mathematics is used.

71.I **Les Rayons Cosmiques.** L. Leprince-Ringuet. (A. Michel, Paris, France, 1945), 373 pp. **Cosmic Rays.** L. Leprince-Ringuet, English translation by F. Ajzenberg. (Prentice–Hall, Inc., Englewood Cliffs, New Jersey, 1950), 290 pp. An introductory chapter on the fundamental physics of particles is followed by a simplified discussion of special relativity. The book contains the results of research on mesons and shower phenomena principally using cloud chamber magnet techniques on mountains in France, but it also describes early results using nuclear emulsions. This is a distinctive book by an experimentalist of distinction; it shows how research is done and discusses the spirit and needs of research workers. The Appendix lists (among the 500 workers at the time) about 40 principal workers and their contributions as of 1945. Mathematics is at a minimum.

72.A **Cosmic Rays.** L. Janossy. (Clarendon Press, Oxford, 1950), 2nd ed., 454 pp. A thorough, critical survey of the cosmic-ray field, originally written during World War II and revised in 1950. The author intends the book to be especially useful to the research worker; complicated mathematical details have been omitted where possible. Contains useful results on geomagnetic theory.

73.I **Cloud Chamber Photographs of the Cosmic Radiation.** G. D. Rochester and J. G. Wilson. (Academic Press Inc., New York; Pergamon Press, Ltd., London, 1952), 128 pp. A complete presentation of cosmic-ray cloud chamber photographs. The authors treat the technical features of cloud chamber operation and present photographs in four sections: electrons and cascade showers, slow μ mesons and their decay, nuclear disintegrations and interaction of secondary particles, and the heavier V particles. These excellent plates are suitable for lectures in cosmic-ray or nuclear physics.

74.A **The Polar Aurora.** C. Störmer. (Oxford University Press, London, 1955). The life work of Carl Störmer is summarized in this volume. Besides detailed descriptions of the polar aurora with many photographs, it contains the mathematical development of particle orbits in the dipole field for which Störmer is well known to cosmic-ray physicists. The applications to cosmic rays are developed in Chap. XII.

75.A **Extensive Air Showers.** W. Galbraith. (Academic Press Inc., New York, 1958; Butterworth Scientific Publications, London, 1958), 211 pp. A complete discussion is given of the development of extensive air showers. Both theory and experimental methods and results are presented. The book is primarily intended for physics students who wish to find out what has been done in this field of research.

76.A **The Study of Elementary Particles by the Photographic Method.** C. F. Powell, P. H. Fowler, and D. H. Perkins. (Pergamon Press, Inc., New York, 1959), 669 pp. This exceptional volume summarizes the work of the world's leading laboratory in the utilization of the photographic emulsion techniques of detecting and identifying charged particles and of studying nuclear interactions. The book includes numerous superb photographs ($8\frac{1}{2}\times 11\frac{1}{2}$ in.) of tracks in emulsions made by cosmic-ray particles and the disintegrations they produce. Important experimental data on the nature of the secondary radiation in the atmosphere, i.e., type of particles, energy distribution, angular distribution, etc., are clearly summarized.

77.E **Cosmic Rays.** G. ZHDANOV. (Lawrence and Wishart, London, 1959), 147 pp. Well-written for the average reader. The author has avoided all mathematical calculations giving only basic physical concepts.

78.A **High-Energy Particles.** B. ROSSI. (Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1952), 569 pp. Additional prints 1956, 1961. Comprehensive account of high-energy phenomena, primarily for the research worker. Provides numerous formulas, tables, and graphs necessary in cosmic-ray research. Contains the theory of electromagnetic interactions, experimental methods, elementary particles, cascade showers, artificial electromagnetic and nuclear interactions, and cosmic-ray nuclear interactions. It is the recognized standard book for the nuclear and interaction aspects of cosmic-ray physics.

79.I **Cosmic Rays.** T. E. CRANSHAW. (Clarendon Press, Oxford, 1963), 125 pp. The state of knowledge in cosmic radiation as of 1963. Nature of the primary beam, theories of the origin of cosmic rays, extensive air showers, geomagnetic effects, and various time variations. Intended to provide a background in cosmic rays for students unfamiliar with the subject.

80.A **Cosmical Electrodynamics.** H. ALFVEN AND C.-G. FALTHAMMAR. (Oxford University Press, England, 1963), 2nd ed., 228 pp. In the second edition of this famous book, Alfven has expanded the fundamental ideas, in collaboration with Dr. Falthammar, and omitted much of the specific applications. Subjects treated include the motion of charged particles in magnetic fields, magneto-hydrodynamics, plasma, magnetic plasma, introduction and references. This is an essential reference for the cosmic-ray physicist, particularly for the geo- and astro-physical aspects.

81.A **Interplanetary Dynamical Processes.** E. N. PARKER. (Interscience Publishers, New York, 1963), 272 pp. Treats the coronal expansion into interplanetary space. Discusses the solar wind, the solar magnetic field, shock waves, and the effects of these processes on the propagation and diffusion of galactic and solar-produced cosmic rays. Discusses the theory of Forbush decreases, the solar cycle modulation, and other effects. References many of the author's original papers, and documents the progress of his thinking while developing the "solar wind" hypothesis.

82.A **The Origin of Cosmic Rays.** V. L. GINZBURG AND S. I. SYROVATSKII. English edition translated by H. S. H. Massey and edited by D. Ter Haar. (Pergamon Press, Inc., New York, 1964), 426 pp. The English edition of this important text includes material up to the time of the International Conference on Cosmic Rays in Jaipur, India, December 1963. The authors have an active interest in all aspects of cosmic-ray research, but in this book discuss the primary radiation in some detail, cosmic rays in the universe and synchrotron emission, motion of cosmic rays in the interstellar medium, and the origin and galactic propagation of protons, electrons, heavy nuclei, x rays, and γ rays. Several appendixes of useful data and an extensive bibliography of 524 papers in astrophysics and cosmic rays are included.

83.A **Space Physics.** D. P. LEGALLEY AND A. ROSEN Eds. (John Wiley & Sons, Inc., New York, 1964), 752 pp; and **Space Science.** D. P. LEGALLEY, Ed. (John Wiley & Sons, Inc., New York, 1963), 668 pp. These books comprise a series of lectures, given in two separate years, for the University of California Engineering and Physical Sciences Extension Series. The two volumes contain a total of 34 articles on space-physics related subjects such as primary cosmic rays, solar physics, solar cosmic rays and flares, extensive reports of the Van Allen belts, the interplanetary medium, the aurora and the upper atmosphere, geomagnetic phenomena, space vehicles, physics of the planets, and origins of the solar system. The lectures are given by experts in the field from universities and private industry. *Space Physics* is a summary of results from 150 U. S. launched space vehicles. The mathematical level is intermediate to advanced.

84.E **Cosmic Rays.** B. ROSSI. (McGraw-Hill Book Co., Inc., New York, 1964), 268 pp. (paperback). An up-to-date introductory account, written in popular style but nevertheless containing an excellent historical survey with authoritative accounts of most of the major milestones in the field. Discusses the discovery of cosmic rays, geomagnetic effects, nuclear and high energy interactions in the atmosphere, origin of cosmic rays, and the Van Allen radiation belts. A good beginning book for a student entering the field at any level, with a useful Appendix and second chapter on nuclear radiation, units, and definitions. Mathematics is avoided wherever possible, but the book contains much physics.

V. TEACHING AIDS

A. Popular Books and Articles

85.E **Nobel Foundation–Nobel Lectures in Physics.** (American Elsevier Publishing Company, Inc., New York, 1964.) Vol. 1, 1901–1921; Vol. 2, 1922–1941; and Vol. 3, 1942–1962. Complete lectures of Nobel prize winners in physics. Also includes presentation speeches and bibliographical sketches. **Nobel Prize Winners in Cosmic Rays and Related Fields: 1933:** P. A. M. Dirac (with E. Schrödinger)—Theoretical work predicting the positron. **1936:** V. F. Hess (with C. D. Anderson)—Discovery of cosmic radiation.

1936: C. D. Anderson (with V. F. Hess)—Discovery of the positron in cosmic radiation. **1948:** P. M. S. Blackett—Improvement of the Wilson cloud chamber (counter control) and for the resulting discoveries in the field of nuclear physics and cosmic rays. **1949:** H. Yukawa—Theoretical work predicting the existence of mesons. **1950:** C. F. Powell—For development of the photographic method in the study of nuclear processes and for his discoveries concerning mesons. **1954:** W. Bothe (with M. Born)—Analysis of cosmic radiation; "the coincidence method."

86.E **"Mesons."** U. CAMERINI AND H. MUIRHEAD, Phys. Today **16** (May 1950).

87.E **"Heavy Elements from Space."** E. P. NEY. Sci. Am. **184**, 26 (May 1951).

88.E **"High Energy Cosmic Rays."** B. ROSSI. Sci. Am. **201**, 134 (November 1959).

89.E **"Solar Particles and Cosmic Rays."** K. A. ANDERSON. Sci. Am. **202**, 64 (June 1960).

90.E **"Supernovae as Cosmic Ray Sources."** M. M. SHAPIRO. Science **135**, 175 (19 January 1962).

91.E **"Plasmas in Space."** H. S. BRIDGE. Phys. Today 31 (March 1963).

92.E **"Radiation Belts."** B. J. O'BRIEN. Sci. Am. **208**, 84 (May 1963).

93.E **"Solar Wind."** E. N. PARKER. Sci. Am. **210**, 66 (April 1964).

94.E **"Cosmic Electromagnetic Radiation."** E. M. HAFNER. Science **145**, 1263 (18 September 1964).

95.E **"Neutrinos from the Atmosphere and Beyond."** F. REINES AND J. P. F. SELLSCHOP. Sci. Am. **214**, 40 (February 1966).

B. Chapters in Physics Text Books

96.A **Nuclear Physics.** E. FERMI. (The University of Chicago Press, Chicago, Ill., 1950), rev. ed., *Chapter 10*. A concise discussion of cosmic radiation is given at the advanced level. Although data on the primary momentum and charge spectrum are somewhat outdated, the discussion of the nuclear interactions of the primary cosmic rays and their secondary components is good. The mathematical theory of charged particle orbits in the geomagnetic field is developed, deriving the allowed and forbidden cones and the mathematical expression for the threshold momentum. A good discussion of the intensity of allowed radiation is given utilizing Liouville's theorem.

97.I **Introduction to Modern Physics.** F. K. RICHTMYER, E. H. KENNARD, AND T. LAURITSEN. (McGraw-Hill Book Co., Inc., New York, 1955), 5th ed., *Chapter 11*. This well-known text contains an excellent introduction to cosmic rays at the intermediate level, and includes a good discussion of early work in cosmic rays such as altitude and latitude variations. A simplified theory of geomagnetic effects on cosmic rays, qualitatively explaining the east–west effect and geomagnetic threshold momenta is given. Shower theory and the role of the mesons in nuclear physics are discussed. The chapter is concluded with a brief discussion of the origin and acceleration of cosmic rays.

98.I **Atomic and Nuclear Physics.** R. S. SHANKLAND. (The Macmillan Company, New York, 1960), 2nd ed., *Chapter 12*. An up-to-date survey of cosmic rays discussing the primary charge composition, geomagnetic effects, short term variations, and the trapped radiation belts. The origin of cosmic rays is discussed along with a thorough discussion of air showers and meson physics.

99.E **Elements of Modern Physics.** A. T. GOBLE AND D. K. BAKER. (The Ronald Press Co., New York, 1962), *Chapter 20*. An up-to-date elementary discussion of cosmic radiation, including basic shower theory, geomagnetic effects and a discussion of strange particles and their decay schemes. A brief outline of the earth's trapped radiation regions is given.

C. Films on Cosmic Rays and Related Subjects

100.E **"Solar Prominences."** 11 min, b & w (1948). University of Michigan, Ann Arbor, Michigan. Gaseous clouds which float from the solar surface are photographed by time lapse. Various kinds of prominences are described.

101.E **"Cosmic Rays."** 27 min, b & w or color (1961). McGraw-Hill Book Co., New York. A detailed examination of present concepts of the origin and nature of charged particles reaching the earth from outer space. Recent discoveries—using balloons, rockets and satellites—are presented. The relationship between cosmic-ray research and nuclear research is outlined.

102.E **"Solar Flares."** 13 min, b & w (1959). Michigan University, Ann Arbor, Michigan. Explains sunspots; plages, the bright areas that always surround sunspots; filaments, long, dark markings often found near the plage regions; and prominences, masses of hydrogen gas which project beyond the edge of the sun.

103.E **"Magnetic Force."** 27 min, b & w (1961). McGraw-Hill Book Co., New York. Explains the nature of the earth's magnetic field, beginning with early speculations; describes the magnetic field within the earth and in space; and shows how the magnetic field controls the path of charged particles that make up the aurora.

104.E **"Strange Case of the Cosmic Rays."** 59 min, color (1957). American Telephone and Telegraph Co., New York. Tells the story of cosmic rays, their character and behavior. Points up the work of scientists in pure research, the constant search for more knowledge of matter and energy. Scientific information is presented by means of live action and animation, film exerpts, and still pictures of cosmic-ray tracks.

105.E **"Our Mr. Sun."** 60 min, color (1956), American Telephone and Telegraph Co., New York. This film tells the story of the sun and its effects on all life on the earth. It shows solar eclipses, sunspots, and tremendous explosions on the face of the sun.

106.E "Time Dilation, An Experiment with μ-Mesons." 36 min, b & w, D. H. Frisch, *MIT* and J. H. Smith, *University of Illinois.* (Produced by Educational Services, Inc., Watertown, Mass.) Using the radioactive decay of cosmic-ray μ mesons, the dilation of time is shown in a filmed experiment which takes place on top of Mount Washington, N. H., and at MIT in Cambridge, Massachusetts. Data are taken to determine the time distribution of the decays of μ mesons at rest. The counting rate for μ mesons with speeds of about 0.99 the speed of light which arrive on top of Mount Washington is determined and the number that survive to reach sea level is measured. From the experimental results the conclusion is drawn that the mesons, moving at 0.99 c keep time at about one-ninth the rate they do when they are at rest.

Infinitesimal Lorentz Transformation

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By means of a series of arguments, a general Lorentz transformation is derived in the infinitesimal. This gives the generators of the group, and exponentiation produces a finite transformation.

A LIE group can be completely defined by the commutation relations of its "generators" I_j:

$$[I_i,I_j]=\sum_k c_{ij}{}^k I_k,$$

where $c_{ij}{}^k$ are constants called "structure constants." To be consistent the structure constants need to satisfy the Jacobi identity which arises from the identity

$$[[I_i,I_j],I_k]+[[I_j,I_k],I_i]+[[I_k,I_i],I_j]=0,$$

and obviously $c_{ij}{}^k=-c_{ji}{}^k$. An element of the continuous group is then given by $\exp(\sum_k I_k \mathcal{E}^k)$, where $\mathcal{E}^k$ is a parameter.

Many times in the theory of Lie groups, generators of the infinitesimal transformation are obtained by replacing, in the equations of a finite transformation, the values for the infinitesimal one. Exponentiation of the generators gives one back the original finite equations. Circular processes like this vitiate the motivation for obtaining the infinitesimal transformation.

By a series of plausibility arguments, we derive directly the infinitesimal Lorentz transformation to a moving frame.[1] Exponentiation is then used to obtain the finite transformation. The series of arguments is:

(1) For a transformation to a frame, $\sum'$ moving infinitesimally slowly with respect to the frame $\sum$, the relativistic equations should reduce to the classical in the limit of small velocity. This gives

$$x'=x-\Delta vt=x-\Delta\beta\tau,$$

where $\Delta\beta=\Delta v/c$ is an infinitesimal and $\tau\equiv ct$.

(2) Both coordinates (space and time) are on an "equal footing." Since to x there is an admixture of the time component, τ, to obtain x' we similarly expect τ' to have an admixture of x. We write $\tau'=\tau+a\Delta\beta x$, where a is to be determined.

(3) The length $s^2=\tau^2-x^2$ is to be preserved in the transformation. An equivalent statement is that the velocity of light is the same in every frame of reference. This gives

$$(s')^2=s^2=(\tau+a\Delta\beta x)^2-(x-\Delta\beta\tau)^2.$$

This determines $a=-1$.

We have now completed our calculations of the infinitesimal transformation. In matrix form,

$$\begin{pmatrix}\tau'\\x'\end{pmatrix}_{\Delta\beta}=(I-\Delta\beta\sigma)\begin{pmatrix}\tau\\x\end{pmatrix},$$

[1] It should be pointed out that the complete set of generators for rotations in four dimensional space–time must include also rotations in space.