22. COMMISSION DES METEORES ET METEORITES

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INTRODUCTION

Data for the present summary were obtained from a number of members of Commission 22, and also from extensive literature which has grown greatly in the last three years (1961–1963). Communications, reprints and recommendations were sent by Astapovich, Babadjanov, Bakharev, Bogorodsky, Bronshten, Kashcheev, Krinov, Lebedinez, Tsesevich (U.S.S.R.), Fireman, Jacchia, McCrosky, Newkirk, O'Keefe, Olivier, Rinehart, Whipple (U.S.A.), Halliday, Millman, Nicholls (Canada), Ceplecha, Kresák (C.S.S.R.), Lovell (England), Hoppe (D.D.R.), Guigay (France), de Jager (Netherlands), Lindblad, B. A. (Sweden), Nielsen (Denmark), Hirose (Japan), Venter (South Africa), Öpik (Eire), Tomsen (New Zealand).

Dr I. S. Astapovich (Kiev University, U.S.S.R.), following the example of previous years, prepared specially for Commission 22 a vast survey of data that appeared in more than 800 papers recently published. Dr P. B. Babadjanov (Astrophysical Inst. Acad. Sci. Tadjik S.S.R.) prepared a survey of Soviet work on meteors. I thank very much all the above mentioned persons for their useful collaboration.

GENERAL NOTES

The three years (1961–1963) were a period of accumulation and analysis of a great amount of information about meteors obtained by known methods. Study of meteoric matter developed in the same direction, but was of a more fundamental and wider character.

The investigation of the distribution of meteoric matter in cosmic space near the Earth resulted in certain success and so did the improvement of the physical theory of meteors and the practical usage of meteoric phenomena for communication. All these are reflected in monographs by Dauvillier (**1**), McKinley(**2**), Bronshten (**3**), surveys by P. Millman, McKinley and E. L. Krinov, in *The Solar System* by G. P. Kuiper and B. M. Middlehurst (**4**), and in a number of other papers (**5, 6, 7**). The monograph by Levin (**8**) was published with some additions in a German translation. Of great importance were papers of international symposia devoted to meteors and cosmic dust, which took place in Amsterdam (Holland) and Cambridge, Mass. (U.S.A.) (**9, 10, 395**).

Results of the observations of meteors carried out in accordance with the IGY-IGC programme appeared in a number of publications (**11, 12, 13, 14, 15, 16, 17, 18**). A comparatively great increase in the number of visual observations was registered during the IGY period: about 116 thousand all over the world, the collection centre being in Ottawa (Millman), and more than 18 thousand over the Soviet Union alone, the centre being in Simferopol (Martynenko). The American Meteor Society, headed by C. P. Olivier, continued its active work. New catalogues of observations of meteors and fireballs by the Society are being prepared for

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publication. Visual observations of meteor streams were systematically carried out by many amateur observers in the Japanese Meteor Committee of the Oriental Astronomical Association, headed by K. Komaki. The Meteor section of the Astronomical Society of South Africa (Venter) continued to carry out visual observations and publish their results.

During 1964–1965, the IQSY will be carried out and will include the studies of the drift and turbulence of the upper atmosphere through observations of meteor trains. In accordance with this programme many countries which participated in the IGY, and, among them, the U.S.S.R., U.K., Canada, C.S.S.R., U.S.A. and others, will carry out a great deal of research work. Some observations carried out during the IGY should be repeated where possible. This is necessary for investigating the stability of a number of parameters characterizing the density of meteoric matter in space and the interaction between meteoric particles and the atmosphere.

In 1961, a symposium devoted to meteor astronomy and meteor physics was organized by the Smithsonian Astrophysical Observatory (Cambridge, U.S.A.) (**9**). Then, also in Cambridge in April 1962, there was a symposium devoted to meteoric matter in the vicinity of the Earth (**395**). Two scientific conferences devoted to the studies of meteors (**20, 21**), and one devoted to meteorites, took place in the Soviet Union (1961: Dushanbe; 1962: Leningrad; 1963: at Kiev). A symposium on meteorites took place at Arizona State University (U.S.A.) in 1961 (**396**). Problems of meteor astronomy and the physics of meteors were also discussed at a number of other international and national conferences including those on aeronautics, on the results of the IGY, and on the Moon and planets. An astronomical dictionary by Kleczek containing cosmic matter terms was published in six languages in C.S.S.R. (**22**). P. Millman (**23**) published a survey of meteor terminology in English, Russian, French and German.

Special expeditions for the observation of telescopic meteors (which numbered up to 40 amateur astronomers each) were sent into the mountains of Czechoslovakia under the leadership of Grygar, Kohoutek and Kvíz.

METEORIC MATTER AND THE EARTH

Studies of meteoric matter made by direct methods have expanded our knowledge about the interaction between meteoric matter and the Earth.

Data obtained by geophysical rockets and artificial satellites (Sputniks)

Meteoric particles have been registered by means of geophysical and cosmic rockets and sputniks. During the recordings, different types of systems were used, of which those employing microphones were the most effective. Films made of different metals were recovered from rockets which came back to the Earth. Small acoustic systems, designed by Vlohovich, were used in geophysical rockets, a number of which were launched at Churchill, Manitoba, Canada.

Direct counts have been made of particles with masses from 10^{-6} g to 10^{-9} g, and with dimensions ranging from 100 to 0·1 μ, which correspond to meteors of magnitude 16 and larger. The experiments give λ, the number of meteoric impacts per second over a unit area one square metre. The quantity λ varies from 2×10^{-4} to 0·6.

A short survey of some results is given below:

Sputnik		λ	Source
Explorer-I	(1958)	0·030—0·008	(**24**)
	1958δ	0·0025	(**25**)
	1959μ	0·0017	(**26**)
Sputnik-3	(1958)	$\leq$0·004	(**27**)
Midas-II	(1960)	0·250	(**28**)

The quantity λ depends on the dimensions of the particles registered. According to the data obtained by an Aerobee rocket (1961) for particles less than 1 μ in diameter, one gets $\lambda = 1000$, and for diameter 10 μ, $\lambda = 10$. According to McCracken, Alexander and Dubin (**29, 30**), the flux of meteor particles at a height of 80 km with masses of particles (m), within the limits of 10^{-10} g $\leqslant m \leqslant 10^{-6}$ g is determined by the relation: $\log \lambda = -1{\cdot}70\, m - 17{\cdot}0$. The quantity λ also depends on the type of system used. Certain changes connected with the change of distance from the Earth and time are also found. T. N. Nazarova (**31**) believes that, at heights of 100–300 km, $\lambda = 0{\cdot}01$, and at heights of 400–2000 km, λ decreases down to 0·001, but still remains one order larger than the possible number of particles in the Zodiacal Cloud. Nazarova also notes changes of λ in space and time of the order of 10^{-3} to 10^{-5} according to data obtained by Soviet cosmic rockets (**1, 2, 3, 32, 33**). In February 1958, Explorer-I recorded an unknown meteor stream with an increase of λ by a factor 50 (**384**). The 'Vanguard-3' satellite (1959), on 1959 November 10-20, recorded an increase in λ of approximately a factor 20, probably due to a traverse of the Leonid orbit (**34**). The maximum number of collisions was registered at $22^{h}\,37^{m}$ U.T. on 1959 November 17, when it had increased more than 1000 times, in comparison with the usual number; the dimensions of registered particles of the Leonid stream are estimated at about 1 μ (**35**). Mariner-II (U.S.A.) launched to Venus recorded between the orbits of the Earth and Venus four orders of magnitude fewer collisions than near the Earth (**36**).

Rather interesting results were obtained by the cosmic rocket Mars-I, launched in the Soviet Union on 1962 November 1, (**37**). During the first 100 minutes, at distances of 6·6 to 42 thousands of km from the Earth, it recorded 60 collisions with particles of mass of more than 10^{-10} g; at that time it was traversing the Taurid stream; having left it the rocket did not record any collisions for 52 minutes. Till 1963 January 30, the meteor data transmitter of the Mars-I rocket was switched on regularly; in 1963 January, at a distance of 23 to 45 millions of km from the Earth, 104 collisions were recorded during $4^{h}\,13^{m}{\cdot}5$ of exposure with a maximum number on 1963 January 20 (7 collisions in 10 minutes). Apparently the transmitter of Mars-I registered a new interplanetary meteor stream.

The density of cosmic dust, at a height of 3000 km, according to Singer (**38**), is larger than that in the atmosphere. At a height of 6000 km, this density is equal to $\rho = 2{\cdot}6\ 10^{-20}$ g cm^{-3}. The Midas-II satellite (1960 – I), launched on 1960 May 24 into an equatorial orbit at a height of 500 km, was specially equipped for recording micrometeorites with 3 acoustic detectors and 2 detectors with wire grids. According to Soberman and Della Lucca (**39**), neither of the grids was damaged, which corresponds to $\lambda < 5{\cdot}10^{-4}$ for particles of diameter more than 10 μ. The acoustic system, with 67 collisions, registered a stream of particles of more than 5 μ diameter, where $\lambda = 0{\cdot}25$, assuming the velocity of these particles to be 15 km sec^{-1}.

Soberman and others (**40**), describe an experiment with a rocket on 1961 July 6. This rocket was equipped with a mylar screen for registering collisions with micrometeorites and with hermetically sealed traps for collecting particles. It reached a height of 168 km, then the screen and the traps were brought back to the Earth and carefully examined by means of an electron microscope, neutron activation and local X-ray analysis. Small solid globules (mainly of a diameter of 0·1 μ) were discovered, along with shapeless particles (0·15 μ) and downy 'flakes' (0·35 μ). These particles have a low geocentric velocity and form a layer of dust in the upper part of the atmosphere.

Launching rockets into the zone of noctilucent clouds in August 1962 in a northern part of Sweden made it possible to find (**41**), at a height of 75–95 km, particles of Fe and Ni with dimensions of more than 0·05 μ and with from 4 to 30 × 10^{10} on a surface with an area of 1 m^2. This number is 2 to 3 orders higher than that obtained by a control launching of a rocket when there were no such noctilucent clouds. The distribution according to diameter (d) follows the law $N \sim d^{-p}$, where $p = 3$ to 4.

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Meteoric Cloud around the Earth

A cloud of dust around the Earth, which was discovered by direct measurements, is described by Whipple (**42**). V. I. Moroz (**399**) points out three zones in this cloud:

(1) $\lambda = 1 - 0{\cdot}1$ (height $h = 100-400$ km);
(2) $\lambda = 10^{-2} - 10^{-4}$ ($h = 400-13\,000$ km);
(3) $\lambda = 10^{-4} - 10^{-6}$ ($h < 13\,000$ km).

But McCracken and others (**43, 44**) underline the fact that different measurements give different results and doubt that such a dust cloud around the Earth exists. Cohen, on the other hand (**45**), points out the difference in the mass distribution of particles near the Earth and at a distance of 108 000 km. Hibbs (**46**) believes that the cloud around the Earth, which is very much like the rings of Saturn, concentrates near the equator. V. G. Fesenkov regards the 'Gegenschein' as a reflection of the solar light from the dust tail of the Earth which is directed away from the Sun (**47**). Kordylewski (**48**) announced the discovery of dust clusters near the libration points of Lagrange in the Moon's orbit. These clusters were discovered as faint luminous spots with a diameter of 5° during a careful examination of Alpine photographs of the sky taken with 1:1·5 cameras.

I. O. Kleiber (1881) and V. G. Fesenkov (1920) had noted the possibility of meteoric particles being captured by the atmosphere of the Earth. This was recently confirmed by Fremlin and others (**49**), and Katasev (**50**). More detailed calculations of the trajectories of particles in a system of three bodies were made by Dole (**51**). He found that, out of all particles near the Earth out to a distance up to 100 Earth radii (638 000 km), 18% enter the atmosphere, and the rest change their primary geocentric velocity. As a result of this, a quasistationary dust cloud is formed around the Earth, in which particles remain from 5 to 400 days, with a geocentric velocity only a little higher than 11 km/sec. S.-S. Huang (**52**) showed that the capture of a meteoric body is possible only at a distance of less than 400 000 km from the Moon (**53**). And besides, in order to get into the zone of capture and stay in it, the velocity of the body must change twice. Ruskol (**54**) explains the concentration of particles of the dust cloud by the fact that they loose their velocities during their mutual collision in a region around the Earth at a distance of less than 200 Earth radii (1 280 000 km).

Singer made a calculation of the concentration of particles of dust around the Earth taking into account the influence of the geomagnetic field (**56**). The concentration of meteoric dust around the Earth takes place, due to the fact that meteoric bodies moving around the Sun in the zone of the orbit of the Earth have very low geocentric velocities. As a result of this gravitational concentration the density of meteoric bodies around the Earth may be 2 to 3 orders of magnitude higher than somewhere further from the Earth. But Singer notes (**57**) that the theory does not explain the maximum density of meteoric dust at heights of 2000 to 3000 km. Newkirk and Eddy (**58**) believe that in the meteoric cloud around the Earth, the concentration of particles is 10^3 times higher than in interplanetary space. Whipple considers the ejection of dust from the Moon's surface through its bombardment by meteorites to be a source of particles in the dust cloud around the Earth. The life time of a captured particle is one revolution and then it is captured at perigee or may be perturbed by the Moon into an orbit with longer life. The Poynting-Robertson effect and the solar wind (corpuscular radiation of the Sun) according to Beard, stimulate a concentration of particles (**60**). According to Whipple, the concentration of particles at a height of 100 km is 10^5 times higher than in the Zodiacal Cloud, and their normal density along the orbit of the Earth is 10^{-21} g cm^{-3}. This may be compared with estimates made by V. G. Fesenkov (**61**), who gives the density of cosmic matter near the Earth as $0{\cdot}7$ to $3{\cdot}5 \times 10^{-20}$ g/cm^2.

Meteoric Matter in the Atmosphere of the Earth

In the upper atmosphere are found micrometeorites, that is particles slightly changed after their penetration from cosmic space, as well as products of the destruction of meteoric bodies: small hardened silicate and ferrous globules blown off the fusing surfaces of such bodies and fragments of fragile and friable particles, probably condensed from their vapours (**62**). The energy of cosmic dust penetrating with a high velocity into the upper layers of the atmosphere raises its temperature. Rasool (**63**) thinks that the energy of the heating by a stream of meteoric dust is 10 erg cm^{-2} sec^{-1}, which can raise by 5° the temperature of a layer 10 km deep. In the presence of a dust activity, the energy of heating increases up to 600 erg cm^{-2} sec^{-1}. In fact, during periods of stream action, artificial Earth satellites (sputniks) register 5–8% increases of the density of the higher layers of the atmosphere.

Not more than 1% of the particles collected in the stratosphere resembled micrometeorites. In the Arctic, Hemenway *et al.*, at a height of 18 km, discovered micrometeorites of ·01 μ diameter and smaller (**64**).

Carleton (**65**) believes that cosmic dust comes into the atmosphere of the Earth from the dust cloud encircling the Earth.

The hypothesis of E. G. Bowen, that cosmic particles are nuclei of condensation of atmospheric precipitation, is still under discussion. The estimated time of fall of cosmic particles in the atmosphere from the moment of their entering the upper layers of the atmosphere until their entering the troposphere varies from 30 (**50**) up to 40–66 days (**66**). Back in 1958, Mrkos, on the third Soviet Antarctic Expedition in Mirny (latitude 60°S), noticed the strengthening of lines in the spectrum of the night sky with the increase of the number of telescopic meteors.

Observations in Haute-Provence also confirm that the content of Na in the upper layers of the atmosphere, at a height of 105 km, increases during periods near the maxima of strong meteor showers (**68, 69**). Data obtained by rockets in the upper parts of the atmosphere show the presence of Mg II and the absence of Mg I (**70**).

Meteor danger.

After the first cosmic flight of Gagarin (U.S.S.R.), in April 1961, and further flights of Soviet and American cosmonauts, the interest in possible meteoroid danger has grown considerably. Fortunately, meteoroid danger is estimated to be small.

Whipple (**71**) has reestimated the meteoroid danger and offered a new theory for the collision and penetration of bodies with high velocity. Mar found for the first Canadian satellite (*S*-27) that the probability of being penetrated by a meteoroid during the first year of its revolution around the Earth was insignificant (**72**). For particles corresponding to meteors up to magnitude 10–11, one finds $\lambda = 0{\cdot}047$. White finds the probability for a 24-hour middle-sized satellite being hit to be once in three years. According to Bjork and Gazley, the 93 m^2, 9 mm thick steel casing of a spacecraft may be penetrated once a year. According to Kresák and Kresáková (**73**), meteor danger varies with a change in the density of sporadic meteor bodies in the ratio of 1:2 and is lowest in January–May. The danger from meteor showers is insignificant and is much less than it may seem from visual and photographic observations. Experiments and calculations show that armour casing with many layers which are some distance one from another would be most effective.

Erosion of spacecraft casings is also caused by a flux of solar corpuscules. Every corpuscular impact is able to remove from the surface of a solid body 50 to 200 atoms. During an experimental bombardment of ferrous meteors by ions of argon (A^+), Heymann and Fluit (**75**) found the intensity of corpuscular erosion to be 1 to 2 mg/coulombs. Experiments carried out by Pitkin and others (**76**) show that erosion of materials is directly proportional to the masses of the ions and inversely proportional to the solidity of a target. Experiments for 24 different ions with energies of 5 to 25 eV were carried out by Roll, Flot and Kistemaker. Meteoroid and corpuscular erosion is especially serious on the surfaces of optical instruments or solar batteries, which must be protected from it by glass plates.

Fall-out of meteoric matter on the Earth's surface

Collection of dust on the surface of the Earth and with the aid of aircraft shows that a considerable part of it is of terrestrial origin. According to Crozier (**77**), who collected small ferronickel globules in Mexico, for particles larger than 5 μ one obtains λ = 0·008, which at first sight corresponds to data obtained by rockets and sputniks. But the latter register particles which do not fall on the Earth but form a dust cloud around it, so such a coincidence is most probably accidental. Parkin and Hunter (**78**), gathering dust in Sicily in 1961, found an increase in the number of globules containing nickel 3 weeks after the dates of the activity of the Perseids, Taurids and Arietids. At the same time, Morikubo (Japan) and Kizirlimak (Turkey) do not confirm the dependence of the amount of cosmic dust on large meteor streams.

The presence, in modern samples, of industrial dust including ferrous globules (from electric and gas welding and metal cutting), leads investigators to study rocks of previous geological epochs. Skolnick (**79**) found in cretaceous sedimentary rocks of California globules of diameters 50 to 850 μ, Hunter and Parkin (**400**) found globules of 14 to 65 μ in the tertiary rocks of Barbados Island. Laevastu and Mellis (**80**) found that the number of fossilized globules is inversely proportional to their masses, so that the total mass for any diameter is a constant. The same results were obtained by rockets for masses of meteoric particles with dimensions of the order of 5 to 15 μ. According to Hunter, magnetic globules in deep water sediments of the ocean are probably of double origin: small grains of magnesium-rich olivine with a density of 3 g cm^{-3} are of terrestrial origin; oxidized nickel-iron with a density of 6 g cm^{-3} is of cosmic origin.

Taking into account these data, it is possible to estimate more precisely the increase in the mass of the Earth as a result of meteor accretion. In the last report of Commission 22 (**81**) an estimate is given of the total mass (M) of meteoric matter annually falling on the Earth, which in 1961 seemed to be most probably of the order of 10^6 to 10^7 tons with a minimum estimate of $M = 10^3$ tons. Newkirk and Eddy (**82**), through photographic, visual and radar data, estimate the influx of meteoric matter of the order of 10^3 ton per day or 3×10^5 tons per year. In the terrestrial atmosphere meteoric dust precipitates very slowly, thus forming, at a height higher than 25 km, the main mass of aerosols with dimensions greater than 0·6 μ. According to Parkin and Hunter (**83**), who collected dust in Sicily, the cosmic component gives M = 350 to 400 tons. On the other hand, Thiel and Schmidt (**84**), who, by means of drilling, discovered ferrous globules in the fossilized ice of the Antarctic, estimate M = 180 000 tons. An estimate of the increase of the terrestrial mass, as a result of meteoric accretion, as being of the order of 10^5 to 10^6 tons per year seems most probable.

The problem of tektites

In the course of recent years, tektites are, with increasing frequency, looked upon as solidified bits of matter melted during the cosmic collisions of the small bodies of the solar system (large meteoroids, nuclei of comets, and asteroids) with the surfaces of large planets and their satellites. It is likely that tektites were formed as a result of meteoric bombardment of the surface of the Earth or of the Moon. Vorobjev (**86, 87**) found that, according to some chemical properties, tektites differ to a certain extent from all known rocks. They have for example a constant content of beryllium (Be^9) including its cosmogenical isotope (Be^{10}), while rocks are known to have an extremely variable content of beryllium. In some specimens of Philippinites, Vorobjev discovered magnetite globules with nickel. Starik and others (**88**), who studied the content of uranium (U) and lead (Pb) in tektites and also the isotopic content of lead, believe that the data is not contrary to the lunar origin of tektites, or their origin as a result of a collision of the cometary nucleus with the surface of the Earth. O'Keefe (**89, 90**) believes that a stream of luminous fireballs (Cyrillids), on 1913 February 9, was a penetration into the atmosphere of fragments of a natural satellite of the Earth, and that tektites could appear as a result of the fall-out of such fragments.

PHYSICS OF METEORS

The development of the physical theory of meteors

Stanjukovich and Shalimov (**91**) studied the movement of meteoric bodies in the atmosphere. In the upper part of the trajectory, they investigated this process as a collision of separate molecules of the air with a meteoric body, and in the lower part of it described the phenomenon by the equation of gas dynamics. They found a new drag coefficient $C_x = 2$ as used by aerodynamicists and estimated the radiation of the shock wave which appears during the flight of a meteoric body to be 6 to 7 orders higher than that following the explosion of TNT. Different aerodynamic conditions of streamlining were compared by Rajchl (**92**) with peculiarities of meteor spectra. Pokrovskij (**93, 94**) showed that the reaction force of evaporating molecules can accelerate or decelerate the movement of the meteoric body in the atmosphere as a result of rotation of the body and its heterogeneous structure. This can explain the increase of velocities of meteors described by Kramer. Bronshten (**95**) studied the structure of the shock wave created by a large meteoric body and estimated its ionization and heat transmission. The physical theory of the flight of meteoric bodies appearing as fireballs was also studied by Oleak (**96**) at the Observatory of the German Academy of Sciences in Babelsberg (D.D.R.). On the basis of the gas dynamic theory, a picture of the stream around a spherical meteoric body was drawn. The equilibrium temperature, taking into account the processes of dissociation and ionization, is 200 000°K. The intensity of emission lines observed in the spectra of meteors was estimated and a comparison of theoretical and observed intensity gave a good correlation. The continuous gas flow according to the theory must pulsate, which causes fluctuation of meteor luminosity in a period of the order of 0·1 to 10^{-5} sec.

Öpik, on the basis of his theory, calculated tables which theoretically predict the luminosity of meteors. This is very well correlated with recent experiments with artificial meteors (**97**). He also published notes on the theory of collisions forming craters (**98**). Verniani, using observed values of drag from photographs of faint meteors taken by Super-Schmidt cameras, estimated the ratio of the coefficient of luminosity to the density of meteoric bodies (τ/ρ_m^2) from the equation of drag and luminosity, taking into account their successive fragmentation. Supposing that the density of meteoric bodies does not depend on their velocity, Verniani found, in the equation $\tau = \tau_0 v^n$, an exponent $n = 1{\cdot}0 \pm 0{\cdot}15$, i.e. the figure which had been earlier used by Whipple and Jacchia from studying photographs of bright meteors by small cameras. Applying this method to an asteroidal meteor (Harvard, N 1242), Cook, Jacchia and McCrosky (**99**) found $\log \tau_0 = -19{\cdot}1$, that is very close to the figure obtained by McCrosky and Soberman (**101**) from their experiments with the Trailblazer rocket ($\log \tau_0 = -18{\cdot}9$). Rajchl (**100**) found a decrease of the coefficient of luminosity near the end of the trajectory, which is contrary to the results found earlier by Anantha Krishnan.

At Maryland University, E. J. Öpik and E. Stoliarik are making theoretical estimates of the drag and ablation of micrometeors. Problems of the fragmentation of meteoric bodies during their flight are being investigated by A. F. Cook II and others (**99**), and Southworth (**175**). Studying meteor photographs from the Ondřejov Observatory, Hoppe (**397**) finds a dependence between the primary mass of a meteor (m) and the height of the end of its trajectory (H_e) in the form: $\log m = 6{\cdot}56 - 0{\cdot}079\, H_e$. Comparison of these data with theory shows that the destruction of a meteoric body takes place first of all due to air resistance and then of melting and evaporation of its separate fragments. A theory for this process is not yet available. For its development it is necessary to have statistical material on the change in the brightness of meteors with height. Levin (**103**) pointed out the necessity of registering the fragmentation of meteoric bodies while reducing meteor observations, and studied the influence of fragmentation upon estimation of the density of the atmosphere. He also investigated the possibility of the determination of the fragmentation of meteoric bodies from light curves of the meteors (**104, 105**), and showed that the visible trajectory of a fragmenting meteor is shorter than the theoretical one. Teplizkaya (**106**), Sandakova and others (**107**) estimated through photographic observations that the density of meteoric bodies is of the order of 0·001 to 1·25 g/cm^{-3} and becomes one order of magnitude less along the trajectory as a result of fragmentation of the meteoric body.

Bronshten (**108**), studying the falling of the meteorite Kaalijarv on the Saarema Island in Estonia (U.S.S.R.), estimated that its primary mass was of the order of 1000 tons. An intensive fragmentation of the meteorite took place at a height of 5–10 km and only 20 to 80 tons fell on the Earth with only the main mass having cosmic velocity. Divari (**109**), from the forms of craters, estimated the falling velocities of a number of fragments of the Sikhote-Alin meteorite and found them to be of the order of 100 to 1000 m/sec.

Destruction of meteoric bodies, during their passage through the terrestrial atmosphere, is accompanied by the melting of their surfaces, the blowing off of melting particles and the evaporation of the matter. Riddell and Windler (**110**) show that the ablation of meteoric bodies of the diameter of 10 to 100 cm takes place comparatively slowly when geocentric velocity is smaller than 20 km/sec and when it is controlled by the convective transfer of heat. With a velocity larger than 20 km/sec, the intensive ablation takes place mainly by radiative transfer of heat and such bodies are usually destroyed completely. Cook (**99, 111**), for velocities smaller than 20 km/sec, uses estimates of Probstein and Kemp (**112**) expressed as a function of the Knudsen number. Special estimates were made by Fay, Moffat and Probstein (**113**) for large meteoric bodies and velocities greater than 20 km/sec. The influence of ablation on the drag coefficient of meteoric bodies is taken into account separately for velocities less than and greater than 20 km/sec. For small meteoric bodies, radiation is the main factor influencing ablation (**114**). Ablation of stone and cometary meteoric bodies in a flow of free molecules according to Cook (**115**), is approximately determined by the primary mass of the body (m_∞), its geocentric velocity outside the atmosphere (V_∞) and the zenithal distance of the radiant (Z_{R}), as: $m_\infty V_\infty^3 \cos^p Z_R$; it is better to take $p = 0{\cdot}5$, though the result will be almost the same with $p = 0$. Buchwald (**116**) estimated the speed of the melting of the Tulle meteorite (Greenland) as of the order of 1·6 mm/sec. Mason and Wijk (**117**) noticed that in the crust of the Miller meteorite (Arkansas), which contained olivine and orthopyroxene, only the latter melted, which gives a melting temperature of the order of 1500–1600°C.

Rosinski and Snow (**118**) believe that minute products of evaporation of meteoric matter start concentrating into specks of dust of 4 to 80Å in diameter. Such particles usually number up to 1500 per cubic centimetre, but on the days of streams they may reach 50 000 per cubic centimetre. They may become the condensation nuclei of water vapour which forms noctilucent clouds. A dust meteor train formed by such particles was photographed by Metzger in Tel Aviv (**119**). Bumba (**120**) observed a dust train against the solar disk on 1961 August 31, in the form of two strips about 5 m wide, assuming the height of the train as about 100 km. Verniani (**121**) believes that the impacts of molecules against the surface of meteoric bodies cause micro-explosions, which greatly increase the drag at high velocities; evaporation stops at velocities smaller than 5·4 km/sec. Rajchl (**122**) showed that the Knudsen number is a parameter of luminosity and evaporation. He also notes (**123**) that the parameter μ, which characterizes the correlation between the cross-section of a meteoric body and its mass, changes in the course of flight and decreases greatly during bursts. Meteoric bodies which produce meteors with bursts, according to Rajchl, have comparatively great perihelion distances and evidently differ in their structure from bodies producing meteors with constant luminosity along the trajectory.

Bronshten (**124**) studied four possible mechanisms for the transfer of heat in meteoric bodies and points out that usually there are not enough parameters used to characterize it (Γ, Λ). Theoretical estimates of the transfer of heat in bodies with supersonic velocities, correlated with experimental data related to the entrance of cone-shaped bodies into the atmosphere, are given in (**125**). Experimental data concerning phenomena accompanying a rocket borne re-entry were obtained by McCrosky and Soberman (**126**) and can be used for the estimation of the luminosity of meteoric bodies. Transfer of heat inside meteoric bodies takes place rather slowly compared to their time of flight in the atmosphere, which can be illustrated by the example of the Migei meteorite, U.S.S.R., where the temperature, according to Du Fresne and Anders (**127**), was never higher than 300°C.

Cook writes that American scientists, while studying meteors, use a standard atmosphere (**128**), and also data from the artificial satellites of the Earth (**129**).

Poloskov and Katasev (**130**) used the physical theory of meteors for the estimation of air density from meteor data. They compared the result with that obtained from rockets and came to the conclusion that it is quite possible to do away with the hypothesis of fragmentation of the meteoric particles. Similar work was carried out in the U.S.S.R. by Kramer and others (**131, 132**), Babadjanov (**133, 134**) and Konopleva (**135**). Kovshun (**136**) estimated scale heights from meteor data. Dependence of the density of the upper layers of the atmosphere on the latitude of the place from which observations are carried out was studied by Babadjanov and Kramer (**137**). In addition, they suggest there may be a dependence of the density of the atmosphere upon the landscape and climatic conditions of the place of observation.

Levin (**138**) studied the problem of the interaction of meteoric matter and the atmosphere from the view point of the estimation of the parameters of the latter.

Latyshev and Lubarsky (**139**) showed that variations in the heights of faint meteors correlate well with the time of day, hour angle of the Moon and solar activity. Shtepan (**140**), through observations of 457 telescopic meteors in the zenithal region, also discovered a dependence of the ratio of heights of appearance and disappearance of meteors upon the hour angle of the Moon.

Experiments with artificial meteors

Results of experiments with artificial meteors were published by McCrosky and Soberman (**141**). A stainless steel bullet, mass of 2·2 g was fired from a rocket by a cumulative charge at a height of 190 km, with a velocity of 9·8 km/sec, and was photographed as a meteor of magnitude 0·4 at heights of 69·4 to 62·6 km. It made it possible to find the lower limit of the coefficient of luminous efficiency applicable to photographic magnitudes, $\tau_0 = 8 \times 10^{-19}$. Introduction of corrections for the composition of meteoric bodies gives τ_0: for ferrous meteorites: $7{\cdot}4 \times 10^{-19}$; for stony: $1{\cdot}2 \times 10^{-19}$, for the cometary meteoroids: 8×10^{-21} to $1{\cdot}6 \times 10^{-19}$.

Zwicky (**142**) described results of an experiment with artificial meteors launched at high velocity from a rocket by means of a cumulative charge at the height of 60 km. These meteors were photographed by Super-Schmidt cameras and the 48-inch Schmidt camera at Mt. Palomar. In the course of 950 m, the velocity of the body changed from 14·4 km/sec down to 13·0 km/sec and its luminosity from magnitude 2 to magnitude 3, which gives the ratio of the luminous energy to kinetic energy $\tau = \tau_0 v = 9 \times 10^{-10}$ from the theory of Öpik, and the luminosity coefficient in the photometric units generally used, $\tau_0 = 7{\cdot}10^{-11}$. Eichelberger and Gehring (**143, 144**) described experiments with bodies of the masses of the order of 10^{-11} g to 10 g and with velocities of 3 to 20 km/sec. Jensen and Palmer (**145**) observed the formation of a small cloud of particles of 1 μ diameter, accompanying impacts of steel bullets against a steel target with a velocity of 15 km/sec, and Nicholls and others (**172**) have obtained spectra of such flashes. Chapman and Larson (**146**), using supersonic velocities, experimentally produced a particle with the shape and form of a tektite.

Meteor Luminosity

Rubzova (**147**) studied curves of meteor luminosity with the help of a photo-electric installation which was calibrated by artificial meteors. Astavin-Rasumin (**148**) carrying out photo-electric observations, and for protection against the luminosity of the night sky used a light filter which cuts off radiation longer than $\lambda = 6200$ Å. Hicks (**149**) used a TV set with a field of 7° and a scanning frequency of 30 frames per second. The screen was photographed 24 times per second with an exposure of 0·02 sec. On 1960 November 22, 14 meteors were observed in 70 minutes of observation; probably only meteors down to magnitude 7 could be seen. Spalding and Hemenway (**150**), using a 50 mm objective (*F*:1·1), observed meteors down to magnitude 6 with the same scanning frequency as Hicks. Photo-electric methods of meteor observation are now looked upon as rather promising.

Photographic methods were used for studies of the luminosity and colour index of meteors. Sandakova (**151**) investigated the reduction of meteor brightness to the international system. Kramer and Teplizkaja (**152**) studied curves of the luminosity of 83 meteors with 11 bursts and discovered that the mean intensity of evaporation is the same along the whole trajectory. Kohoutek (**153**) found in the Palomar Sky Atlas 427 images of meteors which were photographed in red or blue light by a Schmidt camera with aperture 126 cm and focal length 244 cm. Faint meteors are redder; the colour index, taken as 0 for meteors of magnitude 0, increases by 0·12 per magnitude.

Spectra of Meteors

The spectroscopy of meteors has developed successfully. According to Millman (**154**), by 1962 the total number of meteor spectra reached 496. Rajchl (**155**) described meteor spectra obtained with the help of diffraction gratings with a dispersion of 50 and 15 Å/mm. Ceplecha (**156, 157**) introduced a method for the determination of wave length in the case of diffraction gratings, and also the theoretical distribution of luminosity in a spectrum taken with a grating with lines of triangular cross-section (**158**). Together with Rajchl (**159, 160**), he studied spectra of two bright meteors. A detailed analysis of the burst of a Taurid of magnitude −12 was made by Ceplecha (**161**) from a spectrum with a dispersion of 11 to 38 Å/mm. From 70 iron lines, the temperature of excitation was found to be 2970°K ± 160°. The percentage content of elements in the meteoric body was calculated; its composition was very close to that of stone meteorites. The mass of evaporated gas was found to be about 15 kg with a volume of a cylinder 8 m diameter and 100 m long and a velocity of 22 km/sec. The light damping was caused mainly by electron collisions. The main source of free electrons (the total number of which in the burst reached 10^{25} to 10^{26}) was calcium. The electron temperature might have been greater.

At three meteor stations in Canada spectography of meteors was systematically carried out with 40 diffraction spectographs and more than 130 spectra were photographed in 1961–1963. The Leonid shower was very strong in 1961, which made it possible to get 11 spectra during two nights. Three spectographs with jumping film were constructed by Halliday and Griffin (**163**). Two of them were designed for the determination of the decay rate of the forbidden line of oxygen (O I), $\lambda = 5577$ Å, while the third one is designed to secure photographs of the spectra of persistent meteor trains. Halliday, studying the spectrum of a bright Geminid, found that luminosity in the wake concentrates near the outer surface of the quickly enlarging cylinder, the diameter of which reaches 80 m (**164**). A similar effect is observed in the spectrum

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of a Lyrid with greater dispersion (10–20 Å/mm). Millman (**154, 162**) continued to collect and list spectra which had been obtained in all countries of the world. Smirnov (**165**) found in two Perseid spectra an increase of ionization along the meteor path through the ratio of the brightness of lines Mg I (λ = 5173 Å) and Mg II (λ = 4481 Å). Ivannikov (**166, 167**) published data on 20 spectra of meteors, in 4 of which there is a band of molecular nitrogen N_2. Liubarsky points out the presence of sodium (Na II) in some spectra studied by him. Systematic photography of meteor spectra was begun by L. Kresák in 1963 at Skalnate Pleso (C.S.S.R.), where there is a complete set of small cameras with objective prisms, and 4 big cameras (focal lengths = 25 – 30 cm) with replica gratings having 150 lines/mm. Shrirama Rao and Lokanadkan (**398, 169**) secured the first meteor spectrum in India. It was of a Leonid of magnitude −2, in 1961, November 15/16; in the intervals between segments of the meteor spectrum a recombination spectrum of the train with the excitation potential not higher than 5·09 eV was seen. Millman and Halliday (**170**) found, in the near infra-red part of spectra of 9 meteors, lines of atmospheric gases N I, O I; and also lines of Ca II which are intense only in fast meteors. The triplet 7774 Å of oxygen (O I) appears first, and with an increase of meteor luminosity, the intensity of Ca II increases more than that of other lines. Halliday (**171**) found within the spectrum range 3680 Å–8710 Å in Perseid spectra, lines of N II and O II with an excitation potential of more than 20 eV, and also Sr II. Only fast meteors, at a height of 120–79 km, have the green line of oxygen O I (5577 Å) which may have a duration of about 1 sec. Nichols *et al.* (**172**) obtained spectra of the luminosity of the powder of different materials present in meteorites, excited in a tube by a shock wave, and studied the processes of interaction of the hot gas and solid particles. For the estimation of the ablation caused by a shock wave the dimensions of particles were measured before and after the experiment. Laboratory investigations of the air spectrum help to identify the lines of atmospheric gases in meteor spectra.

Radio methods

Radio methods of studying meteors continued to be widely used. According to the programme of radio observations of meteors carried out at Harvard University (U.S.A.) under the direction of Whipple, Hawkins and Southworth, they annually obtain trajectories and orbits of about 10 thousand individual meteors corresponding to visual meteors of magnitude 6 to 12. Southworth (**174, 175**) theoretically calculated diagrams for the Fresnel diffraction picture for improving the accuracy in the reduction of observations. The physical nature of these faint meteors is different from that of the brighter ones, and is now being investigated. Though it might seem they should be of fragmenting character, like those being photographed by the Super-Schmidt cameras, they undergo drag like bright photographic meteors and theoretically are not fragmented bodies. Faint meteors recorded by radar appear only a little higher in the atmosphere than those photographed by the Super-Schmidt cameras though, according to the extrapolation of the heights of the latter, they should appear 10 km higher (**176**).

A new powerful radar equipment working at 32 MHz (λ = 9·4m) with a peak-power of several megawatts was installed at the Springhill Meteor Observatory of the National Research Council (Canada). It is used for detailed studies of radio-echoes of bright meteors, and registers many head-echoes. McIntosh and Millman (**177, 178, 179**) studied theoretically and statistically the head-echo and its correlation with other meteor phenomena. About 8 million meteor-echoes registered in Springhill by a radar of lower power (**180**) were tabulated with the help of digital IBM equipment. Millman and McIntosh got average annual and daily variation curves of hourly meteor rates for the period from 1958 to 1962.

At Ondřejov (C.S.S.R.), observations were continued using the old radar equipment, to which a magnetic registering device for estimation of meteor velocities was added (Plavcová, Šimek (**181**)). Tables have been calculated for estimating meteor velocities according to the

Davies method. At R.R.E., Malvern (England), Greenhow and others (**182**) observed meteors on the frequency of 1300 MHz ($\lambda = 23$ cm) with a narrow directed antenna with a field of 0·6°, amplification of 60 000, and peak-power of 2500 kw. Fourteen reflections from overdense trains of meteors from magnitude 3 to magnitude 5 were registered in the vicinity of the Geminid radiant during 20 hours on 1961 December 12–14. Successful observations on the frequencies of 300 and 500 MHz, were also made in a joint investivation by R.R.E. and Jodrell Bank using the 75 m radio telescope (**387**). The results confirm the theory of McKinley and Eshleman regarding radio-echo formation on VHF. The number of reflections at the heights of 97 to 90km from the overdense trains of the Perseids, Delta-Aquarids and sporadic meteors, was inversely proportional to λ^6 and varied from 0 to 7 echoes per hour; the duration of registration of the train was inversely proportional to λ^2.

Radar meteor observations in the Soviet Union were made with a coherent pulse equipment (**183, 184**). Radiants and orbits of individual meteors (**185**), direction and speed of air currents in the terrestrial atmosphere (**186, 187**), properties of the atmosphere (**188**), were investigated. Lagutin, Fialko and others studied errors and problems in the reduction of radar meteor observations (**189, 190, 191, 192, 193**). Dudnik (**194**) suggested an amplitude-phase method for estimating heights of meteors. Belous and V. Sidorov (**195**) recorded amplitude-time characteristics of meteor radio-echoes at two levels. A method for the determination of the co-ordinates of radiants was suggested by Isamutdinov and Brudny (**196**).

McKinley and Webb (**197**) worked out a method for the reduction (to about 1%) of the relative error of meteor velocities derived from the diffraction pattern. Southworth (**198**) determined the drag of meteors through radio-observations from 6 stations. At the moment of their appearance the velocity of meteors has already been reduced by 1 to 3km/sec, and the deceleration may be as high as 5 to 30km/sec^2. Lindblad (**199**) published results of parallel visual and radar observations of meteors. Davies and Hall (**200**) point out a great dispersion in the ratio of luminosity to ionisation for meteors which were simultaneously observed by photographic and radar means.

A most complete programme of observations by different methods continued to be carried out in Canada under the direction of Millman and McKinley at the Springhill Meteor Observatory of the National Research Council. Simultaneous observations were carried out using 2 radars, 9 visual observers and 15 spectrographs. In the course of 3 years 7000 visual meteors were recorded in addition to 30 000 visual observations received from other stations in Canada and the United States.

Anderson in South Africa (**201**), carried out experiments on the registration of radio-signals on meteor waves.

Radiophysics of meteor phenomena

Verniani and Longhi (Florence University, Italy) theoretically calculated the coefficient of ionization β for a ferrous meteoric body in a nitrogen atmosphere. Lindblad (**202**), through simultaneous visual and radar observations of 688 Perseids on a wave-length of 9·2 m, finds a connection between magnitude (M) and the duration of radio-echo (τ) in the form: $\log \tau = -0{\cdot}50\,M + 1{\cdot}08$. A Perseid of magnitude 0 gives $\tau = 10$ sec, of magnitude 4: $\tau = 0{\cdot}1$ sec. Meteors penetrating deeper into the atmosphere leave persistent trains. Results correspond to the theory of diffusion. According to Millman (**203**), the nature of a meteor radar echo is determined by the physical properties of the meteor and conditions in the ionosphere. On the other hand the meteor component of ionization greatly influences the conditions in the ionospheric E layer. There is a correlation between scattering from field-aligned ionization (H-scatter) and meteor activity (Heritage *et al*, **204**). The closer the direction of the flight of the meteor to the lines of the geomagnetic field the better is the correlation. Bain (**205**) suggests that the geomagnetic field tends to maintain trains parallel to itself and that is why radiants in the direction of the lines of force of the field are determined best of all. Tang (**206**) explains prolonged meteor radio-echoes by resonance phenomena in the plasma of the E layer.

Haskind (**207**) used approximate methods in the theory of dispersion for estimating the reflection of electromagnetic waves moving normal to meteor trails, assumed as plasma cylinders of finite radii. He also studied (**208**) the field of diffused waves resulting from plane electromagnetic waves falling on the ionized meteor trail at an arbitrary angle. Sidorov (**209**) carried out a theoretical analysis of the influence of ionosphere winds on meteor trails during the initial portion of their existence. The distribution of electrons in a meteor trail was studied by Sidorov and Fachrutdinov (**210**), and also by Perelman and Anisimov (**211**). Bayrachenko (**212, 213**) studied the influence of the distribution of electron density in a meteor train on the coefficient of reflection, and the influence of the primary radius and velocity of a meteoroid on the amplitude of the radio-echo. McIntosh (**214**) points out the heterogeneity of the head-echo which appears in overdense trains. Cook and Hawkins (**215**) believe that the appearance of the head-echo is due to ionization of atmospheric oxygen by ultra-violet radiation from the meteor. For a Perseid of magnitude 6 they found an intensity of the ultra-violet radiation of more than 8 erg/sec. The initial radius of trains was studied by Kashcheev and Lebedinez (**216**) who found it to be of the order of 10 to 10^2 cm. Greenhow and Hall (**217**) find that the initial radius of a meteor train increases from 1 to 3 m with an increase in height from 90 to 115 km. The initial width of a meteor train was also studied by Cook and others, and by Hawkins. The adhesion of electrons to neutral molecules in a meteor train is a cause of the sharp decrease of concentration of electrons in the meteor train at a height lower than 80 km and higher than 95 km. Fialko (**218**), and also Bayrachenko and others estimate the coefficient of adhesion as 4×10^{-15} cm^3/sec. Bibarsov (**220**) indicated the possibility of estimating the coefficient of adhesion from the relative duration of radio-echoes recorded by 2 radars working at different wave-lengths. Perelman and Anisimov (**221**) note also an influence of recombination in overdense trains. Diffusion in meteor trains, according to Greenhow and Hall (**222**), changes with height. Dokuchajev (**223**) notes that along the lines of the geomagnetic field the diffusion of trains is greater than in the plane normal to them. The influence of diffusion on the determination of velocities of meteors was studied by Dudnik and others (**224**). The scattering of short radio-waves by meteor trails was studied by Kaliszewski (**225**). Kashcheyev and Lagutin (**226**) carried out an experimental investigation of the polarization effect by means of 2 transmitters and found its presence in 50% of the overdense trains. Simultaneous observations of the trains of Perseids by means of equipment with perpendicular and longitudinal polarization at a wave-length of more than 10 m was carried out by Nemirova (**227**). For reflections of a non-stable type, the polarization effect leads to some distortion of the diffraction pattern. Electromagnetic phenomena, following the flight of the giant Tungus meteorite on 1908 June 30, were studied from magnetograms at the observatory in Irkutsk by Plekhanov and others (**228**). These authors explain the observed perturbation of the geomagnetic field by a powerful magnetohydrodynamic wave with further dynamo effect. Magnetic variations began 2·3 min after the flight and reached, according to Ivanov, 87 gammas (H) and 28 gammas (Z) (**229**); they resemble very much variations following the high-altitude nuclear explosions. Obashev (**230**) explains these variations as an interaction between the plasma formed after the flight of the meteor and the geomagnetic field. Jenkins and others (**231**) note an increase in the level of the micropulsations of the geomagnetic field at frequencies of 1 to 50 Hz during the active periods of the Geminids, Ursids, Leonids, σ-Taurids, Orionids and other meteor showers, which confirms earlier observations by Kalashnikov (U.S.S.R.) of the magnetic effect of meteors. Jenkins and Duvall (**232**) explain this magnetic effect, which reaches 10 gamma according to their estimates, by a movement of the charged particles of a train in the ionosphere Dokuchajev (**233**) theoretically investigated the possibility of luminosity from a coronal discharge of a meteor within a radius of 0·5 to 1 km.

Meteor Radio-communication

Studies of communication by means of meteor ionization were carried out at the Institute of Radio Engineering and Electronics, Prague, C.S.S.R. Beckmann (**234**) worked out a quick method of forecasting the conditions for forward-scatter and also estimated the corresponding distribution of amplitudes (**235**). Pokorny (**236, 237**) deduced the generalized Fresnel integral and gave its solution.

The description of equipment and results of the work on the transmission line using meteors between Illinois and New York is given by Gedaminski and Griffin (**238**). With a tape speech recording prepared beforehand, the mean commercial speed of transmission along the line of meteor radio-communication was 2400 words per minute over a 3-year period of use. With transmission on a frequency of 200 MHz, trains with a linear density of electrons of more than 10^{11} per cm act as reflectors; the coefficient of use varies from 5% to 23%. McNarry (**240**), studying the spectrum of meteor forward-scatter echoes at the frequencies of 22, 42, 62, 82 and 102 MHz, arrived at the conclusion that such echoes can be traced over a path up to 2000 km long. Beckmann describes annual and daily variations of meteor radio-echoes. These depend on the distribution of radiants on the celestial sphere and on the direction of the antenna. Bain (**241**) believes that the experimental data agree best with an assumption of spherical symmetry in the distribution of radiants. Bondar, Kashcheyev, Chepura (**242, 243**) studied peculiarities in the absorption of multi-mode forward-scatter radiosignals. They experimentally studied zones of signal scatter over a 900 km base line; overdense meteor trains play the main part in the scatter of signals from the line of communication. Absorption of the pulse transmission of signals by meteor trains during solar flares was studied by Maynard (**244**). Rice and Forsyth (**245**) studied the decay rate of forward-scatter meteor echoes.

The relation between meteors and ionospheric phenomena (and the formation of sporadic-E in particular) was studied by Rubtsov (**246**) and Savrukhin (**247**). It was shown that the critical frequencies of the ionosphere increased by 0·2 to 0·5 MHz on days of the maximum activity of meteor showers.

Meteoric Phenomena in the Ionosphere

Photographic trails of the Geminids were studied by Cook, Hawkins and Stienon (**248**), who estimated their diameters (1 to 6 m) from photographs taken with the 48-inch Schmidt camera at Mt. Palomar. A theoretical estimate by Loshchilov gives for the train of a Geminid, at a height of 94 km, a radius of 1·8 m, and the time of the establishment of thermal equilibrium as 10^{-4} sec (**249**). It proves once more the identity of the ionized trains of meteors observed by radar and optical methods. Kashcheyev and Lysenko (**250, 251**) published statistical results of radio observations of the drift of meteor trains in Kharkov (U.S.S.R.). The regularity of changes of air currents at meteor heights in Kharkov (U.S.S.R.) and Jodrell Bank (England) is very similar. Twelve-hour changes in the velocity of the wind are clearly observed. The average annual amplitude is 10 to 15 m/sec and it is directed northwards at about 6 A.M. Kampe and others (**252**) found large vertical wind gradients and a region of strong winds at a height of 100 km. The influence of gravity waves on the formation of atmospheric currents at meteor heights was studied by Hines (**253, 254, 255**). Cook (**256**) studied the system of air currents in the upper layers of the atmosphere from the observation of the drift of meteor trains. Lagutin, Lebedinetz and Lysenko (**257**) studied the influence of the drift of meteor trains on the accuracy of the radar determination of the velocities and radiants of meteors. Manning (**258**) studied, in his work, tides and air currents in the upper atmosphere derived from meteor data. Greenhow and Neufeld (**259**), using radio observations, characterize the turbulence of air masses at meteor heights.

The drift and turbulence of meteor trains were studied also by the photographic method.

New photographs of 16 persistent meteor trains were taken in the U.S.S.R. by Savrukhin (**260**), Gulmedov (**261**) and Shodiev (**262**). Savrukhin and Nasyrova (**263**) also studied the drift of meteor trains using visual observations. Savrukhin (**264, 265, 266, 267**) found stability in the stratification of winds at meteor heights. The highest velocities of drift were registered at heights of 96 to 99 km and the lowest at heights of 90 to 93 km. A very good correlation of meteor drifts with the movement of discontinuities in the sporadic-E layer was also found. On the basis of visual observations of drifts of 20 meteor trains, Bakharev (**268**) estimated the speed and direction of wind over Tadjikistan (U.S.S.R.). Woodbridge (**269**), through photographic observations of meteor trains over Cape Kennedy (U.S.A.), discovered vertical currents with a speed up to 30 to 50 m/sec.

The chaotic movement of particles in a meteor train during its drift leads, according to Kent (**270**), to the fading of radio-echoes. Chilton (**271**) notes that, during the active period of the Lyrids, Delta-Aquarids and Perseids, phase anomalies take place in the distribution of long radio-waves at the heights of 80 to 83 km . Carpenter and Ochs (**272**) point out that, in the presence of polar aurora, a radio-ray reflected by a meteor train follows several trajectories and the difference of arrival times can be several hundred micro-seconds over a path length of 1300 km.

METEORS IN THE SOLAR SYSTEM

Physical conditions of meteoric particles in interplanetary space

In the course of recent years it has been suggested that most meteoric bodies are of a friable, porous structure and have a very low effective density. Verniani (**273**), for example, believes that only 15% of meteoric bodies are of a compact structure and of high density. Most porous are κ-Cygnids (with density smaller than 0·01 g/cm^3); the Leonids, Virginids and Capricornids have a density less than 0·1 g/cm^3; the densest are the Geminids. The resisting medium considerably affects orbits of such friable meteoric bodies and this is being investigated by Kiang (**274**). As was shown by Harwit (**275**), radiation pressure also affects meteoric bodies greatly. But it was mentioned above that not all scientists consider these objects of friable structure. Ceplecha and Padevet (**277**), comparing theoretical heights with heights determined from photographs taken by Super-Schmidt cameras, believe that such meteoric bodies are of stony structure. One thing is certain: that is that there is a great difference among the properties of particles taken from different meteor showers. Jacchia (**278**), for example, discovered that meteoric bodies revolving around the Sun in long-period orbits appear in general higher than bodies with orbits of the Jupiter family. Robby (**279**) thinks it possible that meteoric bodies exist, composed of solid nitrogen. These have been ejected from comets and, penetrating into the terrestrial atmosphere, they form green fireballs. Considering the small dimensions of meteoric particles, the electric charges carried by them have a very important effect on their movement in the solar system and on the evolution of the meteor cloud. Whipple (**280**) believes that meteoric bodies can have a potential up to some dozens of volts. Biermann and others draw an analogy between the physical properties of the meteor medium and ionic clouds (**281**).

Zodiacal Cloud

The Zodiacal Cloud around the Sun is now looked upon as a quasi-stationary formation which is completely renovated in the course of 10^5 years. The dust component, according to Fesenkov (**282**), plays the major role. Analysing isophotes of the Zodiacal light, Fesenkov believes that its great width in the direction perpendicular to the plane of the ecliptic shows that meteoric particles with strongly inclined orbits, which probably have been ejected by comets, are present in the cloud. Brandt (**283**) proposed a half-empirical model of the interplanetary meteor medium. Briggs (**284**) determined the space distribution of meteor particles, taking into account the Poynting-Robertson effect. Light diffusion is produced, in general, by particles of less than 50 μ. Accurate estimates of the time of fall of such particles towards the Sun are given by Guess (**285**). The distribution of interplanetary matter in space, and the movement of particles in it, are also studied by Manring (**286**). Trajectories of small bodies in the problem of three bodies were investigated by Meffroy (**287**).

The dust theory of the Zodiacal Cloud is questioned by Harwit (**288**), who thinks that comets cannot feed the Zodiacal Cloud with products of their own destruction, since the matter ejected by comets is forced far beyond the boundaries of the solar system by light pressure. Richter (**289**) studied diffusion and polarization of light for particles of different compositions and with dimensions from 10 to 10^{-4} cm. According to these characteristics, silicates and metals greatly differ from each other; the polarization of larger particles reaches 15 to 20% while smaller particles have lower polarizations. Together with Börngen, he also (**290**) made the same investigations in three colours of particles of irregular form. Peterson (**291**) carried out a 3-colour measurement of the Zodiacal light. The colour index and polarization change with the elongation from the Sun, suggests a change in the dimensions of meteoric particles in the Cloud with distance from the Sun. Giese (**292**) and also Giese and Siedentopf (**293**) estimated the dispersion of electromagnetic waves by globules of different sizes and combinations of Ni, Fe, H_2O and SiO_2. The comparison of the results of these estimates with observation shows the importance of the role played by electrons in the diffusion of solar light in the Zodiacal Cloud. Brandt and Hodge (**394**) explain the Gegenschein by the presence of a lens of meteoric dust in the vicinity of the Earth.

The distribution of meteoric particles according to their masses

The frequency of fall on the whole Earth of big meteorites (final mass (m) more than 10 kg) is 3·3 per day according to Hawkins (**294**), who used for his estimates the meteorite catalogue of Prior-Hey. The decrease in the number of meteorites is proportional to m^{-4}, from which it may be concluded that the process of the fragmentation of meteoroids has gone rather far. The annual number of collisions of meteorites with the Earth, according to Brown (**295**), for cosmic masses of 1 g, 1 kg, 1 ton and 10^3 ton, is equal to: 200 000, 400, 1, and 0·0062 respectively. Millard (**296**), taking into account losses, gives the number of meteorites falling per year for the whole Earth as equal to 7500, that is the same number that was accepted before. According to Kohoutek (**297**), the space density of meteors down to magnitude 5 is $1{\cdot}5 \times 10^{-7}$ meteors/km^3. According to radar observations on a wave-length of 10 m, Fialko and others (**298**) in Tomsk (U.S.S.R.), found the mean value of the parameter $s = 2$ ($s = 1 + 2{\cdot}5 \log_{10} \kappa$, where κ is the ratio between numbers of meteors in successive magnitudes).

Large quantities of data on meteor activity were published during the IGY-IGC period. Bright sporadic meteors give, according to Weiss, the parameter s as 2·5.

Millman and Burland (**299**), through 10 000 visual observations of meteors carried out in Canada during the I.G.Y., got $\kappa = 3{\cdot}0$, as also found by Öpik through 20 000 observations by a meteor expedition in Arizona (1932-1934). The investigation of faint radio meteors down to magnitude 15 showed that their number increases inversely proportional to the minimum mass, and that sometimes a great number of especially faint meteors appear, as was shown by investigations carried out by Kaiser (**300**). The total number of meteors down to magnitude 10·8, according to Kaiser, for the whole Earth is $N = 8{\cdot}2 \times 10^9$ per day. Smith (**301**), on the basis of radio observations, thinks that the distribution of meteors according to their masses is the same at any time of the day or year. In meteor streams, larger particles prevail, as was evident, for example, in the data obtained by Weiss (**302**). He obtained, for the showers η-Aquarids, δ-Aquarids and Geminids, $s = 1{\cdot}61$, 1·54 and 1·50 respectively for faint meteors (underdense trains) and 1·4, 1·9 and 1·7 for bright meteors (overdense trains).

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Kresáková (**303**) confirms the absence of telescopic meteors in the Perseid shower. On the other hand in the Scorpiid shower, which belongs to the group of ecliptic streams, Derbeneva and Shodjev (**304**) observed the maximum number of telescopic meteors in 1960 June 30–July 1. Evidently, the distribution of meteors is different in streams correlated with long-period and short-period comets. Kresák (**305**), studied the latitude variations of the total, and optically observable, influx of meteors for 24 meteor showers. The results permit a discussion of the relation of different phenomena to an increased dust content of the atmosphere contributed by meteor showers. The annual variation of the frequency of bright meteors was studied by Kresák and Kresáková (**306**) through 1139 meteor trails photographed at Skalnate Pleso. The variation of the number of bright meteors is in general the same as that of telescopic meteors which are 10^3 to 10^4 times fainter, but is influenced more by the large showers. Six large meteor showers account for about 25% of the photographs of bright meteors, but bring to the Earth only 2% of the mass of meteoric matter.

The distribution in space of very small particles, which correspond to meteors down to magnitude 15 and which are registered by radio methods at a wave-length of 13 m, is extremely irregular, a fact pointed out by Gallagher and Eshleman (**307**). These authors discovered the presence of sporadic showers of meteors from magnitude 10 to magnitude 15, with a strong maximum having a duration as high as 24 hours for some of them.

The total influx on the Earth of meteoric particles down to 3×10^{-4} g, registered by radar on a wave-length of $\lambda = 8$ m, is estimated by Lebedinetz (**308**) to be a mass of 10 000 to 200 000 tons per year.

Orbits of meteoric bodies

The presence in the zone near the Earth of meteoric bodies with direct motion was shown by some new data. Nilsson and Weiss (**309**), from radio observations of 1434 heights of meteors in the Antarctic at Mawson (latitude 68°S), arrived at the conclusion that they have no marked annual variation, indicating that the mean geocentric velocity of meteors is constant. These observations also showed a concentration of radiants near three points, the Sun, the antisun and the apex of the Earth's motion. Many orbits of meteoric bodies are of ecliptic streams with direct motion, as well as the meteorites, for example the Příbram meteorite which is associated with the σ-Leonids. Levin (**310**), working from the physical theory of meteors, notes an extreme prevalence of direct motions in the complex of meteoric bodies and believes that the real density of radiants in the antapex is 10 to 15 thousand times more than in the apex.

Orbits of large meteoric bodies (down to magnitude 4 to 5) were determined by the photographic method. McCrosky and Posen (**311**) published a catalogue of the orbits of 2529 meteors on 6600 photographs obtained in the period 1952–1954 in New Mexico with a base line of 29 km. Final orbits for meteors, photographed by Super-Schmidt cameras, are given by Jacchia and Whipple (**313**). Velocities of meteors were estimated with an accuracy up to 0·1 to 0·4%. A number of orbits of meteoric bodies are correlated with 14 known streams. Many meteors do not belong to compact streams, but their orbits are very much alike which makes it possible to point out 80 meteor associations. More than 90% of bright meteors which have been photographed have orbits of the comet type. 7 hyperbolic orbits have probably errors which cast doubt on their reality.

In Canada the two meteor stations of the Dominion Observatory at Meanook and Newbrook, Alberta continued in operation. The Super-Schmidt cameras were in limited use; photographs obtained earlier were being analysed in Ottawa.

Results of 545 photographic observations of meteors during 1957–1959 in Dushanbe were published by Babadjanov (**317**), who has calculated 181 orbits. Babadjanov and Kramer (**318**) noted 16 new meteor associations, 5 of which are correlated with comets including 1743 I and

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1832 II. A dependence of the mean mass of sporadic meteors upon the aphelion distances of orbits was also pointed out. Results of the photographic determination of meteor orbits at Odessa and Kiev were given by Kramer and Konopleva (**319**), Benjukh and others (**320**), and Krivutsa and others (**321**). Ceplecha and others (**322**) calculated 88 orbits from photographic observations at Ondrejov during the IGY period. According to Hirose (Japan), the meteor patrol continues its work in Mitaka, near Tokyo, with a corresponding station in Kanozana, 60km SE from Mitaka. Since the end of 1962, a new meteor station has been in operation at Mt. Dodaira, 60km NE from Mitaka. A second catalogue of Japanese photographs of meteors is being prepared for publication.

Kohoutek (**323**), from photographs taken at Mt. Palomar, found that radiants of meteors down to magnitude 5 concentrate towards the ecliptic and their orbits have very low eccentricities. McCrosky and Posen have developed a special fast programme for reducing photographs of meteors taken with Super-Schmidt cameras, using a digital computer. According to this system, one chooses in a photograph some stars of appropriate brightness and location, and then the trajectory of the meteor is determined relative to these stars without referring to a map or a catalogue. A computer, in less than a second, reads from magnetic tape the co-ordinates of all the stars that happen to be in the region of the plate and identifies the chosen stars. It is expected that the new programme will make it possible to cut the gap between the collection of observations and the calculations and will help to process 600 meteors per year.

Large numbers of meteor orbits down to magnitudes 9 to 10 were found during recent years by the radio method, in particular at the Kharkov Polytechnical Institute by Kashcheev and others (**324**). According to Lagutin (**325**), orbits of fainter meteors have eccentricities of not more than 0·7; their nearly circular orbits may have high inclinations, from 40° to 150°. For the fainter meteors the asteroidal component probably plays a role together with the cometary component. Isamutdinov (**326**) suggested a new method for the radar determination of meteor orbits.

Hawkins (**327**) described a number of installations for the radar determination of meteor orbits down to magnitude 10. He points out that more than 99% of the orbits of sporadic meteors have direct motions. Smaller bodies move along circular orbits highly inclined to the ecliptic plane.

Orbits of larger meteoric bodies (meteorites) were studied by Wood (**329**), who found them in general of the asteroidal type but partly of the cometary type. The determination of the heights of telescopic meteors carried out in C.S.S.R. gives, according to Grygar and Kohoutek (**330**), 98 ± 4 km for the beginning of the luminous path: 93 ± 4 km for maximum luminosity: and 88 ± 3 km for the end of the flight: with the mean velocity: 36 ± 5 km/sec. Suppositions about the existence of very low telescopic meteors, and also about objects with hyperbolic velocities, were not confirmed.

Meteor Showers

Quadrantids. Radio observations carried out in Florence (**332**) showed, in accordance with previous observations, a strong concentration of meteoric bodies in the central part of the stream.

Eta Aquarids. Simonenko (**333**), from observations of 55 meteors of the Eta-Aquarid shower in May 1962, determined the ephemeris of the radiant; a significant decrease of the radiant area is noted for the period of maximum.

Perseids. According to Terentjeva the Perseids have a lower space density than the Delta-Aquarids, and 75 particles in a cube 1000km to a side. The activity of the Perseids, which seems relatively strong, is explained by their high geocentric velocity. The perturbations of the Perseid stream were studied by Southworth (**335, 336**), who arrived at the conclusion that meteors of this stream were ejected from the nucleus of Comet 1862 III, about a thousand years ago, with the comparatively high velocity of 2·6 km/sec. The ephemeris of the Perseid shower was corrected by Balan (**388**). Bakharev (**337**) confirmed the existence of an eastern branch of the shower and gave its orbit.

Draconids. According to Davies and Turski (**338**), Draconids were ejected from the nucleus of Comet Giacobini-Zinner in 1894, with a velocity of less than 10 m/sec, as shown by calculations for 100 points on the orbit of the stream. These took into account the perturbations of Jupiter, Saturn and the Earth. Yevdokimov (**339**), on the basis of his calculations, believes that the stream first appeared in 1898. Meteoric particles continued to leave the comet after the formation of the meteoric stream. According to Yevdokimov (**340**), 18% of its mass was ejected from the nucleus of the Comet Giacobini-Zinner, in 1939–1946, in the form of particles which replenished the meteoric stream.

Leonids. The activity of the Leonids (in connection with the approach to the Earth of the main concentration of the shower, which will take place in 1965–1967) has increased greatly. On 1961 November 16/17 many bright meteors were observed and the hourly number of visually observed meteors in some places was more than 50. Murakami (**341**) from observations of 1938–1958, studied the structure of the stream. He found the density in the central part of the main concentration to be $7{\cdot}2 \times 10^{-23}$ g/cm^{-3} and further from it to be $6{\cdot}3 \times 10^{-25}$ g/cm^{-3}. The total volume of the stream is of the order of $2{\cdot}9 \times 10^{23}$ km^3, its mass of $6{\cdot}7 \times 10^9$ tons, which could have formed an asteroid with the density of iron and with a diameter of about 0·5 km. The distribution of meteors according to their brightness gives $\kappa = 2{\cdot}2$ for magnitudes $< +1$ and $\kappa = 1{\cdot}5$ for magnitudes $> +1$; so Leonids are very poor in small particles. The age of the stream is estimated to be of the order of 1000 to 1800 years. Probably it appeared when Comet 1861 I was going through perihelion with a velocity of ejected particles of 10 m/sec.

Geminids. Kashcheev, Lebedinetz and Lagutin (**342**), from 298 radio orbits of individual meteors, found a systematic difference in the orbital elements of particles in different parts of the stream. The velocity was estimated with a mean error of $\pm$ 1·8 m/sec, and the position of the radiant with a mean error of $\pm 2{\cdot}5°$. Plavcova (**343**) published results of radio observations of 36 185 meteors which were recorded in December 1959. The maximum activity of faint Geminids takes place 1·5 days earlier than the maximum of bright meteors. The coefficient of the distribution of meteors according to their masses is:

$$s = 2{\cdot}31 \pm 0{\cdot}05 \quad \text{for masses of} \quad 0{\cdot}1 < m < 1{\cdot}3\text{g and}$$
$$s = 1{\cdot}45 \pm 0{\cdot}02 \quad \text{for} \quad 1{\cdot}6 < m < 3{\cdot}9\text{g}$$

Grygar and others (**344**) found for the Geminids: $\kappa = 2{\cdot}78$ down to visual magnitude 3, and for the sporadic background: $\kappa = 2{\cdot}70$ down to visual magnitude 5.

Minor streams. Southworth and Hawkins (**345, 346, 347**) present important statistics of the photographic observations of meteors in relation to the minor meteor streams. They have found a new type of minor stream with a large area of radiation and have suggested a new criterion for identifying such streams against the sporadic background. They call minor streams those which give, from the photographic records, an hourly rate of less than 3 ($n_h \leq 3$). There are 34 such streams and 24 of them are here listed for the first time. Terentjeva (**348**), from 3600 photographic orbits and 2000 of the best visual radiants, found 154 minor streams. Some of the streams have rather large radiant areas, sub-radiants and even radiant-antipodes. The complex of meteoric bodies in the solar system has a well-regulated structure. The sporadic background, corresponding to a chaotic distribution of meteor orbits in space, is the result of the disintegration of meteor streams by planetary perturbations and other factors. Disintegraion of meteor streams is a transient process, with a period of half-disintegration of 70 years.

A number of published papers are devoted to minor streams. Terentjeva (**349**) studied the Delta-Aquarids from all the observations, beginning with the date when they were discovered

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in 1871. Northern and southern branches are noted. The mean density of meteoric matter in the stream is $1{\cdot}2 \times 10^{-23}$ g/cm^{-3}, i.e. a little lower than the density of the central swarm of the Leonids. But because of a low geocentric velocity, the Delta-Aquarids seem to be rather poor in comparison with the splendid Leonids. Because of their small perihelion distance (0·06), meteoric bodies of this stream are heated up to 1100°K, i.e. to the temperature of the melting of silicates. Zotkin and Lipajeva (**350**) also estimated the space density and the luminosity function of the Delta Aquarid meteors. According to Ridley (**351**), Phoenicids, which were discovered on 1956 December 5, are probably connected with Comet Blanpain 1819 IV, which has a period of 5·1 years. Virginids were observed in Holland and Germany from 29 March to 4 April, 1962 (**352**). The well observed minor stream of Cygnids was also recorded (**353**). Pagashevski (**354**) described the history of the investigation and the main properties of meteor streams. Shtepan published observations of 1979 telescopic meteors from 120 radiants during 1952–1960. An abnormally large number of sporadic telescopic meteors was registered by him in 1958, February 26 and September 15. An interesting estimate of the accuracy of the determination of radiants ($\pm$ 1°) and of individual heights ($\pm$ 10km) is given by Stohl on the basis of 733 visual observations of 269 telescopic meteors (**357**). This shows that such observations give quite reliable information.

Observations of Fireballs

During the last three years 68 fireballs have been recorded. Projects of photographic patrols have been worked out for the systematic studies of fireballs in the U.S.A., U.S.S.R. and C.S.S.R. Ceplecha and Rajchl at Ondrejov, tested panoramic cameras covering the whole sky which photograph meteors down to magnitude -6. The rotating shutter gives 12·5 breaks per second; 35 mm film is used. In the central part of the U.S.A. 16 stations are established at a distance of 250km from each other and each of them is equipped with 4 cameras. In order to locate the falling of a meteorite with an accuracy up to some hundred meters, lenses are used with aperture = 2·4 cm focal length = 15 cm (f/6·3) and with a field of 85°. A switching shutter gives breaks, coded according to the time, and it is possible to find the time for every meteor with a duration of flight more than 1·3 sec to an accuracy of 10 sec. Photometers connected with cameras register the beginning of the phenomenon and in the case of extreme brightness of a fireball they reduce 1000 times the sensitivity of the optic system, so that the cameras give good photometric results for meteors from magnitude -20 to magnitude -5.

After the flight of the fireball in 1961, April 12 (**358**), a hole of 40cm diameter was discovered the next day in the ice of the Chasha Lake (Transurals, U.S.S.R.). The daylight fireball, which flew over South Wales (Australia) on 1961, August 5, was photographed by Sprag on 36 frames of colour film. Lindblad (**360**) calculated the trajectory and orbit of the fireball of 1954 January 9 with a brightness of magnitude $-6{\cdot}6$. This was observed over South Scandinavia by more than 300 people, including 3 astronomers. Belkovich (**361**) mentions the radio-location and visual observations in Kazan (U.S.S.R.) of the fireball of 1959 October 8, with a velocity of 60km/sec. According to Pokshivnitskii the detonating fireball which flew over the Carpathians on 1959, September 9, was from the Quadrantids. Pokrzywnicki (**362**) published a survey of observations carried out in Poland from 1304 to 1959. Among them should be noted a hyperbolic fireball in 1935, September 12, and a fireball in 1959, November 6, the sound of which was observed together with its flight. According to Astapovich such fireballs are called electrophonic. To this type belong also the fireball observed on 1960, June 5 over the Ukraine (U.S.S.R.), and 41 objects described by Romig and Lamar (**363**), who give observations of such fireballs in the U.S.A. A. V. Nielsen (Denmark) has prepared for publication a catalogue of 1000 bright fireballs. In New Zealand the determination of the Earth points of the trajectories of fireballs has been started.

Some luminous fireballs were observed as a result of the entering of sputniks into the dense

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layers of the atmosphere: 1960 December 2 ($m = -12$), 1963 October 30 ($m = -10$), and others.

A number of papers were devoted to the problem of the Tungus meteorite. Fesenkov (**364, 365**) believes that the phenomenon was caused by a collision of the Earth with the dust nucleus of a comet which had a diameter of about 0·5 km and a density of some hundredths of a gram per cm^3. The explosion of the cometary nucleus took place in the atmosphere at a height of 10 km (**366**). So Fesenkov, and also Krinov, Idlis and Karijagina (**367**), support the hypothesis of Whipple and Astapovich concerning the cometary nature of the Tungus object. Astapovich (**368**) thinks that the cometary nucleus had a hyperbolic velocity and passed deeply through the atmosphere of the Earth then went into cosmic space again. The energy of the explosion is estimated to be 10^{23} erg (**369**). A group of investigators in Tomsk (U.S.S.R.), who carried out (at the location of the fall) geochemical, radiometric and other observations, published an interesting paper on the problem of the Tungus meteorite, edited by Plekhanov (**370**). At a distance of 2 to 6 km NW from the hypocentre of the explosion there was found in the soil a high content of Ni, Co, and Mn. Metal globules of Fe and Ni have been found at a distance up to 200 km NW (**371**). The radio-activity of the area of explosion corresponds to the planetary background. No craters have been discovered on the ground (**372**). Stanjukovich and Bronshten (**373**) estimated theoretically the energy, velocity, mass and mechanism of the explosion. Zikulin (**374**) modeled the phenomenon on a scale of 1:4000 and believes that the devastation of the forest was caused by a ballistic wave.

The origin and evolution of Meteors

The connection of meteoric bodies with meteorites, asteroids and comets can be studied, according to Terentjeva (1963), through the constant of the integral of Jacobi. This supports once more the hypothesis concerning the double source of meteoric material in the solar system —a result of the destruction of comets and asteroids. Turski (**375**) estimated the connection between the dynamic structure and origin of meteor streams. Southworth (**376, 377, 378**) calculated the planetary perturbations of different meteors in a stream and compared them with the observed ones. He finds the age of the Orionids a little less than 1000 years, of the Perseids less than 6000 years and probably about 1000 years. Levin (**379**) believes that properties of plane meteor streams are determined in general by the parameters of the originating comet. Southworth (**380**) showed that solid particles were ejected by the Arend-Roland Comet 1957 III with velocities and distribution in directions, as predicted by Whipple for an icy model of the comet. The larger of these particles can be compared in dimensions with meteors registered by radar. He also states that any bright periodic comet, which approaches the Earth closer than 0·1 A.U., must be correlated with a meteor stream. Quiring (**381**) denies the role of the accretion of meteoric matter in the formation of planets and attributes a dominating role to the fragmentation of the small bodies of the solar system.

The cosmic age of meteorites, estimated by radioactive methods, seems to support the view that the process of the formation of meteoric bodies has extended over a long period during the life of the solar system. The age of the Sikhote-Alin meteoric body, determined from the ratio K:Ar, is 430×10^6 years (**382**), and the age of the youngest meteorites, Cold Bokkeveld and Farmington, is less than 200×10^3 years (**383**). The group of stone meteorites (from the ratio $H^3:He^3$) has an age of 22 ± 2 million years. According to Geiss, the fragmentation of the originating comet took place this long ago.

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RECOMMENDATIONS

Some members of the Commission have proposed various recommendations. They have been discussed during the meetings of the Commission in Hamburg, and the adopted version of these recommendations is included in the Commission Report, *IAU Transactions*, volume XII B.

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APPENDIX. — REPORT OF THE SUB-COMMITTEE ON METEORITES

(prepared by E. L. Fireman, President of the Sub-Committee)

Introduction

The past three years have not seen so important new discoveries nor so great technical advances in the science of meteorites as the previous three years. The period has rather been one of data accumulation by means of techniques developed earlier, and of more extensive investigations along previously begun lines. It has also been dominated by review articles, books, and symposia, rather than by original research, which is usually expressed in shorter publications. The more spectacular advances described in the previous report of Sub-Commission 22*a* are the bases for most of the recent work.

Schaeffer (**1**), Anders (**2**), and Arnold (**3**), wrote excellent review articles on isotopes in meteorites. Mason (**4**) wrote a splendid book on meteorites. Middlehurst and Kuiper (**5**) edited a collection of extensive articles on the Moon, meteorites, and comets. V. G. Fesenkov and E. L. Krinov (**6**) edited a monograph on the Sikhote-Alin meteorite fall and published a collection of papers on the dust of meteors and meteorites (**7**). O'Keefe (**8**) edited a collection of good articles on tektites. In addition, the proceedings of a number of conferences on meteors and meteorites and other collections of articles were published in book form (**9**). From the number of review articles and books written during the past three years, one might conclude that the origin and history of meteorites are known. This is not true. In fact, very few problems in meteorites can be considered solved.

Meteorite Falls, Finds and Craters

The Pribram meteorite fall, which occurred on 1959 April 7 is the only one for which rotating-shutter, double-station photographs of the flight through the atmosphere exist. This meteorite has a minor-planet-type orbit, as Ceplecha and his co-workers determined, with $a = 2{\cdot}434$ A.U.; $e = 0{\cdot}6742$; $q = 0{\cdot}7899$ A.U.; $\omega = 241°35'$; and $i = 10°25{\cdot}5'$ (**10, 11**). Tuček (**12**) studied the morphology and the mineral composition of Pribram — a crystalline chondrite whose principal constituents are olivine and enstatite. The spallation rare-gas isotopes, measured by Stauffer and Urey (**13**) are $He^3 = 24{\cdot}0 \pm 1{\cdot}2 \times 10^{-8}$ cm^3 g^{-1}; $Ne^{21} = 5{\cdot}40 \pm 0{\cdot}25 \times 10^8$ cm^3 g^1; and $A^{38} = 0{\cdot}79 \pm 0{\cdot}04 \times 10^{-8}$ cm^{3}g^{-1}. These values are within the range given in the extensive study of rare gases in chondrites by Kirsten, Krankowsky and Zähringer (**14**). The potassium in Pribram was not measured; a potassium-argon age of $3{\cdot}7 \times 10^9$ years was, however, estimated by assuming 0·087 per cent potassium. An exposure age of 12×10^6 years was