[iii] PREFACE

The present analysis of the origin and evolution of the solar system represents a fusion of two initially independent approaches to the problem. One of us (Alfvén) started from a study of the physical processes (1942, 1943a, 1946; summarized in a monograph in 1954), and the other (Arrhenius) from experimental studies of plasma-solid reactions and from chemical and mineralogical analyses of meteorites and lunar and terrestrial samples. Joined by the common belief that the complicated events leading to the present structure of the solar system can be understood only by an integrated chemical-physical approach, we have established a collaboration at the University of California, San Diego (UCSD), in La Jolla, during the last seven years. Our work, together with that of many colleagues in La Jolla, Stockholm, and elsewhere, has resulted in a series of papers describing the general principles of our joint approach, experimental results, and model approximations for some of the most important processes.

The present volume is a summary of our results, which we have tried to present in such a form as to make the physics understandable to chemists and the chemistry understandable to physicists. Our primary concern has been to establish general constraints on applicable models. Hence we have avoided complex mathematical treatment in cases where approximations are sufficient to clarify the general character of the processes.

The work was made possible by grants from the Planetology Program Office and the Lunar and Planetary Program Division, Office of Space Science, National Aeronautics and Space Administration Headquarters. Their longstanding help and encouragement particularly that of Steven E. Dwornik and Robert P. Bryson have been of crucial importance, and we are grateful also to Maurice Dubin for support. Our thanks are also extended to Homer E. Newell, John Pomeroy, Ernst Stuhlinger, and Dan M. Herman for their continuing active interest in this undertaking. In view of NASA's association through the years with the preparation of this [iv] study, we are particularly gratified to have it published (at the initiative of Steven E. Dwornik) as a NASA Special Publication.

The molding of the material into an organized and critically edited form is due to the dedicated and competent effort of Dawn S. Rawls. We also owe much gratitude to a number of our colleagues who have contributed in many ways to this work, particularly Bibhas R. De, Wing-Huen Ip, and Asoka Mendis at UCSD in La Jolla, and Nicolai Herlofson, Bo Lehnert, Carl-Gunne F ä lthammar, Lars Danielsson, and Lennart Lindberg at the Royal Institute of Technology in Stockholm. Continual encouragement and advice from Professors Henry G. Booker, James R. Arnold, and William B. Thompson at UCSD have also been of importance in our work.

INDEX PAGE

SP-345 Evolution of the Solar System

[v] Contents

Preface.

1. Introduction.
    1.1. Fundamental approaches to the problem.
    1.2. Planetary system-satellite systems.
    1.3. Five stages in the evolution.
    1.4. Processes governing the evolutionary stages.
    1.5. Model requirements and limitations.

PART A - PRESENT STATE AND BASIC LAWS.

2. The Present Structure of the Planetary and Satellite Systems.
    2.1. Orbital properties of planets and satellites.
    2.2. Physical properties of planets and satellites.
    2.3. Prograde and retrograde satellites.
    2.4. The Laplacian model and the distributed-density function.
    2.5. Discussion of the distributed-density diagrams.
    2.6. Titius-Bode's "law".

3. The Motion of Planets and Satellites.
    3.1. The guiding-center approximation of celestial mechanics.
    3.2. Circular orbits.
    3.3. Oscillations modifying the circular orbit.
    3.4. Motion in an inverse-square-law gravitational field.
    3.5. Nonharmonic oscillation; large eccentricity.
    3.6. Motion in the field of a rotating central body.
    3.7. Planetary motion perturbed by other planets.

[vi] 4. The Small Bodies.

4.1. Survey and classification.
4.2. Evolutionary differences between large and small bodies.
4.3. Main-belt asteroids.
4.4. The Hilda and Hungaria asteroids.
4.5. The Trojans.
4.6. The cometary-meteoroid populations.

5. Forces Acting on Small Bodies.
5.1. Introduction.
5.2. Gravitational effects.
5.3. Electromagnetic effects.
5.4. Limit between electromagnetically and gravitationally controlled motion.
5.5. Radiation effects.
5.6. Conclusions.

6. Kepler Motion of Interacting Bodies: Jet Streams.
6.1. Introduction.
6.2. The interplanetary medium.
6.3. Effects of collisions.
6.4. Orbiting particles confined in a spacecraft.
6.5. Conclusions from the spacecraft model.
6.6. Jet streams and negative diffusion.
6.7. Simple model of negative diffusion.
6.8. Contraction time of a jet stream.
6.9. Collisions between a grain and a jet stream.
6.10. Jet streams as celestial objects.

7. Collisions: Fragmentation and Accretion.
7.1. Production of small bodies: fragmentation and accretion.
7.2. Size spectra.
7.3. Three simple models.
7.4. The transition from fragmentation to accretion.

8. Resonance Structure in the Solar System.
8.1. Resonances in the solar system.
8.2. Resonance and the oscillation of a pendulum.
8.3. A simple resonance model.
8.4. Deviations from exact resonance.
8.5. Orbit-orbit resonances.
[vii] 8.6. The Kirkwood gaps.
8.7. On the absence of resonance effects in the Saturnian ring system.

8.8. Spin-orbit resonances.
8.9. Near-commensurabilities.

9. Spin and Tides.
9.1. Tides.
9.2. Amplitude of tide.
9.3. Tidal braking of a central body's spin.
9.4. Satellite tidal braking of planetary spins.
9.5. Solar tidal braking of planetary spins.
9.6. Tidal evolution of satellite orbits.
9.7. Isochronism of spins.
9.8. Conclusions from the isochronism of spins.

10. Post-Accretional Changes in the Solar System.
10.1. Stability of orbits.
10.2. Resonance and stability.
10.3. Stability of Saturnian rings and the asteroidal belt.
10.4. Constancy of spin.
10.5. On the possibility of reconstructing the hetegonic processes.

PART B- THE ACCRETION OF CELESTIAL BODIES.

11. Accretional Processes.
11.1. Survey of Part B.
11.2. Gravitational collapse of a gas cloud.
11.3. Planetesimal accretion: accretion by capture of grains or gas.
11.4. Gravitational accretion.
11.5. Nongravitational accretion.
11.6. Accretion of resonance-captured grains.
11.7. Necessary properties of an accretional process.
11.8. The present state of asteroids, meteoroids and comets, and the exploded-planet hypothesis.

12. On the Accretion of Planets and Satellites.
12.1. Planetesimal accretion.
12.2. A jet stream as an intermediate step in formation of planets and satellites.
[viii] 12.3. Accretion of an embryo.
12.4. Mass balance of the jet stream.
12.5. Energy balance in a jet stream.

12.6. Accretion when the infall into the jet stream is constant.
12.7. Discussion.
12.8. Numerical values.
12.9. Conclusions about the different types of accretion.
12.10. Early temperature profile of accreted body.
12.11. Conclusions about the temperature profile of planets.
12.12. The accretional hot-spot front.
12.13. Differentiation effect of the accretional heat front.

13. Spin and Accretion.
13.1. Grain impact and spin.
13.2. Accretion from circular orbits by nongravitating embryo.
13.3. Gravitational accretion.
13.4. Giuli's theory of accretion.
13.5. Statistical theory of accretion.
13.6. Jet-stream accretion and planetary spins.

14. Relations Between Comets and Meteoroids.
14.1. Basic problems.
14.2. Positive and negative diffusion; meteor streams as jet streams.
14.3. Accretional mechanism in meteor streams.
14.4. Observations of comet formation in a meteor stream.
14.5. Long- and short-period comets.
14.6. Inferences on the nature of comets from emission characteristics.
14.7. Analogies between cometary and asteroidal streams.
14.8. Comparison with the accretion of planets and satellites.

PART C - PLASMA AND CONDENSATION.

15. Plasma Physics and Hetegony.
15.1. Summary of parts A and B and plan for parts C and D.
15.2. Relation between experimental and theoretical plasma physics.
15.3. The first and second approach to cosmic plasma physics.
15.4. Strategy of analysis of hetegonic plasmas.
15.5. Required properties of a model.
15.6. Some existing theories.

[ix] 16. Model of the Hetegonic Plasma.
16.1. Magnetized central body.

16.2. Angular momentum.
16.3. The transfer of angular momentum.
16.4. Support of the primordial cloud.
16.5. The plasma as a transient state.
16.6. Conclusions about the model.
16.7. The hetegonic nebulae.
16.8. Irradiation effects.
16.9. The model and the hetegonic principle.

17. Transfer of Angular Momentum and Condensation of Grains.
17.1. Ferraro isorotation and partial corotation.
17.2. Partial corotation of a plasma in magnetic and gravitational fields.
17.3. A plasma in partial corotation.
17.4. Discussion.
17.5. Condensation of the plasma: the two-thirds law.
17.6. Energy release during angular momentum transfer.

18. Accretion of the Condensation Products.
18.1 Survey.
18.2. Evolution of orbits due to collisions.
18.3. The Roche limit.
18.4. Model of orbit development.
18.5. Accretion inside $r_{MR.}$
18.6. Structure of the Saturnian rings.
18.7. Accretion outside r_{MR}.
18.8. Formation of the asteroid belt.
18.9. Conclusions about partial corotation.
18.10. Satellite and planet formation.
18.11. Accretion of volatile substances.

19. Transplanetary Condensation.
19.1. Interplanetary and transplanetary condensation.
19.2. Limit between interplanetary and transplanetary space.
19.3. Condensation of bodies in almost-parabolic orbits.
19.4. Bodies with long-period orbits.
19.5. Diffusion of almost-parabolic orbits: encounters with planets.
19.6. Genetic relations of the comet-meteoroid complex.
19.7. Conclusions about the meteoroid populations.
19.8. Genealogy of the bodies in the solar system.

[x] PART D - PHYSICAL AND CHEMICAL STRUCTURE OF THE SOLAR SYSTEM.

20. Chemical Structure of the Solar System.
20.1. Survey.
20.2. Sources of information about chemical composition.
20.3. Chemical differentiation before and after the accretion of bodies in the solar system.
20.4. Unknown states of matter.
20.5. The composition of planets and satellites.
20.6. Composition of the Sun.
20.7. Regularity of bulk densities in the solar system.

21. Mass Distribution and the Critical Velocity.
21.1. Mass distribution in the solar system.
21.2. The bands of secondary bodies as a function of gravitational potential energy.
21.3. Comparative study of the groups of secondary bodies.
21.4. Theoretical background for the band formation.
21.5. Attempts to interpret the band structure.
21.6. Three objections.
21.7. Search for a "critical velocity".
21.8. Experiments on the critical velocity.
21.9. Theory of the critical velocity.
21.10. Conclusions about the critical velocity.
21.11. Chemical composition of infalling gas.
21.12. The chemical composition of the solar system and inhomogeneous plasma emplacement.
21.13. Modification of the critical velocity ionization distance due to interaction with a partially corotating plasma.

22. Meteorites and Their Precursor States.
22.1. Interpretation of the evolutionary record in meteorites.
22.2. Sources of meteorites.
22.3. Selection effects.
22.4. Upper size limits of meteorite precursor bodies.
22.5. Precursor states of meteorite parent bodies.
22.6. Jet-stream evolution and properties of meteorites.
22.7. Cohesive forces in meteoritic material.
22.8. Evolutionary sequence of precursor states of meteorites.

[xi] 22.9. Age relationships in the evolution of meteorite parent jet streams.
22.10. General remarks on the record in meteorites.

23. The Structure of the Groups of Secondary Bodies.
23.1. Ionization during the emplacement of plasma.
23.2. Complete ionization.
23.3. Partial ionization.
23.4. Change of spin during the formation of secondary bodies.
23.5. Observational values of T_K/τ.
23.6. Mass distribution as a function of T_{ion}/τ.
23.7. Discussion of the structure of the groups of secondary bodies.
23.8. Complete list of T_{ion}/τ for all bodies.
23.9. Completeness.
23.10. Conclusions about the model of plasma emplacement.

PART E - SPECIAL PROBLEMS.

24. Origin and Evolution of the Earth-Moon System.
24.1. The hetegonic aspect.
24.2. Comparison with other satellite systems.
24.3. Structure of a normal satellite system of the Earth.
24.4. The capture theory.
24.5. Tidal evolution of the lunar orbit.
24.6. Destruction of a normal satellite system.
24.7. Accretion and the heat structure of the Moon.
24.8. Composition of the Moon.
24.9. Conclusions.

25. The Properties of the Early Sun.
25.1. On the use of solar-system data to study the early.
25.2. Solar mass.
25.3. Solar magnetic field.
25.4. Solar spin period.
25.5. Solar radiation, solar wind.
25.6. Effects produced by a D-burning Sun.
25.7. Remarks on the formation of stars.

[xii] 26. Origin of the Earth's Ocean and Atmosphere.

26.1. Earth's ocean and the formation of the solar system.
26.2. The remote precursor stages.
26.3. The immediate precursor stages.
26.4. Accumulation of water during the accretion of the Earth.
26.5. Introduction of water in the lithosphere.
26.6. The ocean and the Earth-Moon system.
26.7. Summary and conclusions.

27. Concluding Remarks.

References.
Symbols.
Index.

[505-529] REFERENCES

Alexander, A. F. O'D., 1953. Saturn's rings- minor divisions and Kirkwood's gaps, Brit. Astron. Assoc. J. 64: 26.

Alexander, A. F. O'D., 1962. The Planet Saturn: A History of Observation, Theory and Discovery (Macmillan, New York).

Alfvén, H., 1942. On the cosmogony of the solar system, Stockholms Observatorium Ann. 14(2): 3.

Alfvén, H., 1943a. On the cosmogony of the solar system, Stockholms Observatorium Ann. 14(5): 3.

Alfvén, H., 1943b. On the effect of a vertical magnetic field in a conducting atmosphere, Ark. Mat. Astro. Fysik 29A(11): 1.

Alfvén, H., 1946. On the cosmogony of the solar system, Stockholms Observatorium Ann. 14(9): 3.

Alfvén, H., 1954. On the Origin of the Solar System (Oxford Univ. Press, London).

Alfvén, H., 1961. On the origin of cosmic magnetic fields, Astrophys. J. 133:1049.

Alfvén, H., 1962. On the mass distribution in the solar system, Astrophys. J. 136:1005.

Alfvén, H., 1963. On the early history of the Sun and the formation of the solar system, Astrophys. J. 137: 981.

Alfvén, H., 1964. On the origin of the asteroids, Icarus 3: 52.

Alfvén, H., 1968, Second approach to cosmical electrodynamics, Ann. Geophysiq ue 24: 1.

Alfvén, H., 1969. Asteroidal jet streams, Astrophys. Space Sci. 4: 84.

Alfvén, H., 1971. Apples in a spacecraft, Science 173: 522.

Alfvén, H., 1975. Electric Current Structure of the Magnetosphere, Report No. 75 -03 (Division of Plasma Physics, Roy. Instit. Tech., Stockholm) to published in Proceedings of the Nobel Symposium on Physics of Hot Plasma in the Magnetosphere.
Alfvén, H., and G. Arrhenius, 1969. Two alternatives for the history of the moon, Science 165: 11.

Alfvén, H., and G. Arrhenius, 1970a. Structure and evolutionary history of the solar system, I, Astrophys. Space Sci. 8: 338. Note: Numerous illustrations and tables in the text are adapted from those appearing in this paper.

Alfvén, H., and G. Arrhenius, 1970b. Origin and evolution of the solar system, II, Astrophys. Space Sci. 9: 3. Note: Numerous illustrations and tables in the text are adapted from those appearing in this paper.

Alfvén, H., and G. Arrhenius, 1972a. Origin and evolution of the EarthMoon system, The Moon 5: 210.

Alfvén, H., and G. Arrhenius, 1972b. Exploring the origin of the solar system by space missions to asteroids, Naturwiss. 59: 183.

Alfvén, H., and G. Arrhenius, 1973. Structure and evolutionary history of the solar system, III, Astrophys. Space Sci. 21: 117. Note: Numerous illustrations and tables in the text are adapted from those appearing in this paper.

Alfvén, H., and G. Arrhenius, 1974. Structure and evolutionary history of the solar system, IV, Astrophys. Space Sci. 29: 63. Note: Numerous illustrations and tables in the text are adapted from those appearing in this paper.

Alfvén, H., and C.-G. Falthammar, 1963. Cosmical Electrodynamics, Fundamental Principles, 2nd edit. (Oxford Univ. Press, London).

Alfvén, H., and L. Lindberg, 1975. Magnetization of celestial bodies with special application to the primeval Earth and Moon, The Moon 10: 323.

Alfvén, H., and A. Mendis, 1973. The nature and origin of comets, Nature 246:410.

Alfvén, H., M. Burkenroad and W.-H. Ip, 1974. Cosmogony of the asteroidal belt, Nature 250: 634.

Allan, R. R., 1967. Resonance effects due to the longitudinal dependence of the gravitational field of a rotating body, Planet. Space. Sci. 15: 53.

Allen, C. W., 1963. Astrophysical Quantities, 2nd edit. (The Athlone Press, Univ. of London, London).

Aller, L. H., 1967. Earth, chemical composition of and its comparison with that of the Sun, Moon and planets, in Int. Dictionary of Geophysics, Vol. 1, S. K. Runcorn, ed. (Pergamon Press, New York): 285.

Anders, E., 1964. Origin, age and composition of meteorites, Space Sci. Rev. 3:583.

Anders, E., 1965. Fragmentation history of asteroids, Icarus 4: 399.

Anders, E., 1968. Chemical processes in the early solar system as inferred from meteorites, Accounts Chem. Res. 1: 289.

Anders, E., and M. E. Lipschutz, 1966. Critique of paper by N. L. Carter and G. C. Kennedy, Origin of diamonds in the Canyon Diablo and Novo Urei meteorites, J. Geophys. Res. 71: 643.

Anderson, J. D., G. W. Null and S. K. Wong, 1974. Gravity results from Pioneer 10 Doppler data, J. Geophys. Res. 79: 3661.

Angerth, B., L. Block, U. Fahleson and K. Soop, 1962. Experiments with partly ionized rotating plasmas, Nucl. Fusion Suppl. Part 1: 39.

Angus, J. C., H. A. Will and W. S. Stanko, 1968. Growth of diamond seed crystals by vapor deposition, J. Appl. Phys. 39: 2915.

Apollo 16 Preliminary Examination Team, 1973. The Apollo 16 lunar samples: petrographic and chemical description, Science 179: 23.

Arnold, J. R., 1965. The origin of meteorites as small bodies: II- The model, Astrophys. J. 141: 1536. The origin of meteorites as small bodies: III- General considerations, Astrophys. J. 141: 1548.

Arnold, J. R., 1969. Asteroid families and "jet streams," Astron. J. 74: 1235.

Arnold, J. R., M. Honda and D. Lal, 1961. Record of cosmic ray intensity in the meteorites, J. Geophys. Res. 66: 3519.

Arrhenius, G., 1969. Kosmologisk revolution fran manen, Forskning och Framsteg 7: 2.

Arrhenius, G., 1972. Chemical effects in plasma condensation, in From Plasma to Planet, A. Elvius, ed. (Wiley, New York): 117.

Arrhenius, G., and H. Alfvén, 1971. Fractionation and condensation in space, Earth Planet. Sci. Lett. 10: 253.

Arrhenius, G., and C. Andersen, 1973. Unpublished experimental data.

Arrhenius, G., and S. K. Asunmaa, 1973. Aggregation of grains in space, The Moon 8: 368.

Arrhenius, G., and S. K. Asunmaa, 1974. Adhesion and clustering of dielectric particles in the space environment 1. Electric dipole character of lunar soil grains, in Lunar Science V (The Lunar Science Institute, Houston, Tx.): 22.

Arrhenius, G., and B. R. De, 1973. Equilibrium condensation in a solar nebula, Meteoritics 8: 297.

Arrhenius, G., S. Asunmaa, J. I. Drever, J. Everson, R. W. Fitzgerald, J. Z. Frazer, H. Fujita, J. S. Hanor, D. Lal, S. S. Liang, D. Macdougall, A. M. Reid, J. Sinkankas and L. Wilkening, 1970. Phase chemistry, structure and radiation effects in lunar samples, Science 167: 659.

Arrhenius, G., S. K. Asunmaa and R. W. Fitzgerald, 1972. Electrostatic properties of lunar regolith, in Lunar Science III, C. Watkins, ed. (The Lunar Science Institute, Houston, Tx.): 30.

Arrhenius, G., H. Alfvén and R. Fitzgerald, 1973. Asteroid and Comet Exploration, NASA CR-2291, (Govt. Printing Office, Washington, D.C.).

Arrhenius, G., B. R. De and H. Alfvén, 1974. Origin of the ocean, in The Sea, Vol. 5, E. D. Goldberg, ed. (Wiley, New York): 839.

Asunmaa, S. K., and G. Arrhenius, 1974. Adhesion and clustering of dielectric particles in the space environment 2. The electric dipole moments of lunar soil grains, in Lunar Science V (The Lunar Science Institute, Houston, Tx.): 25.

Asunmaa, S. K., S. S. Liang and G. Arrhenius, 1970. Primordial accretion; inference from the lunar surface, in Proc. Apollo 11 Lunar Science Conf. Vol. 3, A. A. Levinson, ed. (Pergamon, New York): 1975.

Axford, I., 1973. Personal communication.

Babic, M., S. Sandahl and S. Torven, 1971. The stability of a strongly ionized positive column in a low pressure mercury arc, in Proc. Xth Internat. Conf. on Phenomena in Ionized Gases, P. A. Davenport and R. N. Franklin, eds. (Oxford, Parsons, Henley-on-Thames, England): 120.

Banerjee, S. K., 1967. Fractionation of iron in the solar system, Nature 216:781.

Banerjee, S. K., and R. B. Hargraves, 1971. Natural remanent magnetization of carbonaceous chondrites, Earth Planet. Sci. Lett. 10: 392.

Banerjee, S. K., and R. B. Hargraves, 1972. Natural remanent magnetizations of carbonaceous chondrites and the magnetic field in the early solar system, Earth Planet. Sci. Lett. 17: 110.

Baxter, D., and W. B. Thompson, 1971. Jetstream formation through inelastic collisions, in Physical Studies of Minor Planets, NASA SP-267, T. Gehrels, ed. (Govt. Printing Office, Washington, D.C.): 319.

Baxter, D., and W. B. Thompson, 1973. Elastic and inelastic scattering in orbital clustering, Astrophys. J. 183: 323.

Berlage, H. P., 1930. On the electrostatic field of the sun as a factor in the evolution of the planets, Proc. Koninkl. Ned. Acad. Wet. Amsterdam 33:719.

Berlage, H. P., 1932. On the structure and internal motion of the gaseous disc constituting the original state of the planetary system, Proc. Koninkl. Ned. Acad. Wet. Amsterdam 35:553.

Berlage, H. P., 1940. Spontaneous development of a gaseous disc revolving round the sun into rings and planets, Proc. Koninkl. Ned. Acad. Wet. Amsterdam 43: 532.

Berlage, H. P., 1948a. The disc theory of the origin of the solar system, Proc. Koninkl. Ned. Acad. Wet. Amsterdam 51: 796.

Berlage, H. P., 1948b. Types of satellite systems and the disc theory of the origin of the planetary system, Proc. Koninkl. Ned. Acad. Wet. Amsterdam 51:965.

Birch, F., 1964. Density and composition of mantle and core. J. Geophys. Res.

69:4377.

Birch, F., 1965. Energetics of core formation, J. Geophys. Res. 70: 6217.

Birkeland, K., 1908. The Norwegian Polaris Expedition, 1902-1903 (Aschehoug and Co., Christiania, Norway).

Bishop, E. V., and W. C. DeMarcus, 1970. Thermal histories of Jupiter models, Icarus 12:317.

Black, L. P., N. H. Gale, S. Moorbath, R. J. Pankhurst, and V. R. McGregor, 1971. Isotopic dating of very early Precambrian amphibolite facies gneisses from the Godthaab District, West Greenland, Earth Planet. Sci. Lett. 12: 245.

Block, L. P., 1955. Model experiments on aurorae and magnetic storms, Tellus 7:65.

Block, L. P., 1956. On the scale of auroral model experiments, Tellus 8: 234.

Block, L. P., 1967. Scaling censiderations for magnetospheric model experiments, Planet. Space Sci. 15: 1479.

Block, L. P., 1972. Potential double]ayers in the ionosphere, Cosmic Elec trodyn . 3: 349.

Bobrovnikoff, N. T., 1942. Physical theory of comets in light of spectroscopic data, Rev. Mod. Phys. 14: 168.

Bogard, D. D., E. K. Gibson, Jr., D. R. Moore, N. L. Turner and R. B. Wilkin, 1973. Noble gas and carbon abundances of the Havero, Dingo Pup Donga and North Haig ureilites, Geochim. Cosmochim. Acta 37:547.

Bostrom, R., 1968. Currents in the ionosphere and magnetosphere, Ann. Geophysique 24: 681

Bostrom, R., 1974. Ionosphere-magnetosphere coupling, in Magnetospheric Physics, B. M. McCormac, ed. (D. Reidel, Dordrecht, Holland): 45.

Bostrom, K., and K. Fredriksson, 1966. Surface conditions of the Orgueil meteorite parent body as indicated by mineral associations, Smithsonian Miscellaneous Collections 151(3): 1.

Boulos, M. S., and O. K. Manuel, 1971. Xenon record of extinct radioactivities in the earth, Science 174: 1334.

Brandt, J. C., 1970. Introduction to the Solar Wind (W. H. Freeman and Co., San Francisco, Calif.).

Bratenahl, A., and G. M. Yeates, 1970. Experimental study of magnetic flux transfer at the hyperbolic neutral point, Phys. Eluids 13: 2696.

Brecher, A., 1971. On the primordial condensation and accretion environment and the remanent magnetization of meteorites, in The Evolutionary and Physical Problems of Meteoroids, NASA SP-319, C. L. Hemmenway, A. F. Cook and P. M. Millman, eds. (Govt. Printing Office, Washington, D.C.): 311.

Brecher, A., 1972a. Memory of early magnetic fields in carbonaceous chondrites, in On the Origin of the Solar System, H. Reeves, ed. (Centre Nationale de la Recherche Scientifique, Paris): 260.

Brecher, A., 1972b. Vapor Condensation of IVi-Fe Phases and Related Problems, Part I of Ph.D. Thesis, Univ. of Calif., San Diego, California.

Brecher, A., 1972c. The Paleomagnetic Record in Carbonaceous Chondrites, Part II of Ph.D. Thesis, Univ. of Calif., San Diego, California.

Brecher, A., and G. Arrhenius, 1974. The paleomagnetic record in carbonaceous chondrites: natural remanence and magnetic properties, J. Geophys. Res. 79: 2081.

Brecher, A., and G. Arrhenius, 1975. The paleomagnetic record in carbonaceous chondrites: modeling of natural remanence and paleofield intensities, J. Geophys Res., in press:

Brouwer, D., 1951, Secular variations of the orbital elements of minor planets, Astron. J. 56: 9.

Brouwer, D., 1963. The problem of the Kirkwood gaps in the asteroid belt, Astron. J. 68(3): 152.

Brouwer, D., and G. M. Clemence 1961a. Orbits and masses of planets and satellites, in The Solar System, Vol. III, Planets and Satellites, B. M. Middlehurst and G P. Kuiper eds. (Univ. Chicago Press, Chicago, Ill.): 31.

Brouwer, I?., and G. M. Clemence, 1961b. Methods of Celestial Mechanics (Academic Press, New York).

Brouwer, D., and A. J. J. van Woerkom, 1950. The secular variations of the orbital elements of the principal planets, Astron. Papers Am. Ephemeris 13: 81.

Brown, E. W., and C. A. Shook, 1964. Planetary Theory (Dover, New York).

Brown, H., I. Goddard and J. Kane, 1967. Qualitative aspects of asteroid statistics, Astrophys. J. Suppl. Ser. 14(125): 57.

Brownlee, R. R.,;., and A. N. Cox, 1961. Early solar evolution, Sky and Tel. 21:252.

Cameron' A. G. W., 1962. The formation of the sun and planets, Icarus 1: 13.

Cameron, A. G. W., 1963. Formation of the solar nebula, Icarus 1: 339.

Cameron, A. G. W., 1973. Accumulation processes in the primitive solar nebula, Icarus 18: 407.

Carlqvist, P., 1969. Current limitations and solar flares, Solar Phys. 7: 377.

Carpenter, R. L., 1970. A radar determination of the rotation of Venus, As bon. J. 75: 61.

Chamberlin, T. C., 1905. Fundamental problems in geology, in Carnegie Institution Yearbook No. 4 (Carnegie Inst. Tech., Pittsburgh, Penn.): 171.

Chapman, C. R., 1972a. Surface Properties of Asteroids, Ph.D. Thesis, Massachusetts Institute of Technology, Cambridge, Massachusetts.

Chapman, C. R., 1972b. Paper presented at the Colloquium on Toro, Tucson, Arizona, Dec. 1972.

Chapman, C. R., and 1. W. Salisbury, 1973. Comparison of meteorite and asteroid spectral rBflectivities, Icarus 19: 507.

Chapman, C., T. V. Johnson and T. B. McCord, 1971. A review of spectrophotometric studies of asteroids, in Physical Studies of Minor Planets, NASA SP 267, T. Gehrels, ed. (Govt. Printing Office, Washington, D.C.): 51.

Chebotarev, G. A., 1967. Analytical and Numerical Methods of Celestial Mechanics (Elsevier, New York).

Clarke, W. B., M. A. Beg and H. Craig, 1969. Excess He3 in the sea: evidence for terrestrial primordial helium, Earth Planet. Sci. Lett. 6: 213.

Cloutier, P. A., 1971. Ionospheric effects of Birkeland currents, Rev. Geophys. Space Phys. 9: 987.

Cloutier, P. A., H. R. Anderson, R. J. Park, R. R. Vondrak, R. J. Spiger and B. R. Sandel, 1970. Detection of geomagnetically aligned currents associated with an auroral arc, J. Geophys. Res. 75: 2595.

Cohen, C. J., and E. C. Hubbard,

1965. Libration of the close approaches of Pluto to Neptune, Astron. J. 70: 10.

Cohen, C. J., E. C. Hubbard and C. Oesterminter, 1967. New orbit for Pluto, Astron. J. 72: 973.

Collins, L. W., E. K. Gibson and W. W. Wendlandt, 1974. The composition of the evolved gases from the thermal decomposition of certain metal sulfates, Thermochim. Acta 9: 15.

Cook, A. F., F. A. Franklin and F. D. Palluconi, 1973. Saturn's rings- a survey, Icarus 18: 317.

Danielsson, L., 1969a. Statistical arguments for asteroidal jet streams, Astrophys. Space Sci. 5: 53.

Danielsson, L., 1969b. On the Interaction Between a Plasma and a Neutral Gas, Report No. 69-17 (Division of Plasma Physics, Roy. Instit. of Tech., Stockholm).

Danielsson, L., 1970. Experiment on the interaction between a plasma and a neutral gas, Phys. Fluids 13: 2288.

Danielsson, L., 1971. The profile of a jetstream, in Physical Studies of Minor Planets, NASA SP--267, T. Gehrels, ed. (Govt. Printing Office, Washington, D.C.): 353.

Danielsson, L., 1973. Review of the critical velocity of gas-plasma interaction, part I: experimental observations, Astrophys. Space Sci. 24: 459.

Danielsson, L. and N. Brenning, 1975. Experiment on the interaction between a plasma and a neutral gas II, Phys. Fluids 18: 661.

Danielsson, L., and W.-H. Ip, 1972. Capture resonance of the asteroid 1685 Toro by the Earth, Science 176: 906.

Danielsson, L., and L. Lindberg, 1964. Plasma flow through a magnetic dipole field, Phys. Fluids 7: 1878.

Danielsson, L., and L. Lindberg, 1965. Experimental study of the flow of a magnetized plasma through a magnetic dipole field, Ark. Fysik 28: 1.
Danielsson, L., and R. Mehra, 1973. The Orbital Resonances between the Asteroid Toro and the Earth and Venus, Report (Division of Plasma Physics, Roy. Instit. of Tech., Stockholm).

De, Bibhas, 1973. On the mechanism of formation of loop prominences, Solar Physics 31: 437.

Defant, A., 1961. Physical Oceanography 1 (Pergamon, New York).

Delsemme, A., 1972. Vaporization theory and non-gravitational forces in comets, in On the Origin of the Solar System, H. Reeves, ed. (Centre Nationale de la Recherche Scientifique, Paris): 305.

Delsemme, A. H., 1973. Origin of short period comets, Astron. Astrophys. 29:377.

DeMarcus, W. C., 1958. The constitution of Jupiter and Saturn, Astron. J. 63:2.

DeMarcus, W. C., and R. T. Reynolds, 1963. The Constitution of Uranus and Neptune, Memoires Soc. R. Sc. Liege, Se ser. V11: 51.

Dermott, S. F., and A. P. Lenham, 1972. Stability of the solar system: evidence from the asteroids, The Moon 5: 294.

Dessler, A. J., 1968. Solar wind interactions, Ann. Geophysique 24: 333.

Dohnanyi, J. S., 1969. Collisional model of asteroids and their debris, J. Geophys. Res. 74: 2531.

Dole, S. H., 1962. The gravitational concentration of particles in space near the Earth, Planetary Space Sci. 9: 541.

Dollfus, A., 1961. Visual and photographic studies of planets at the Pic du Midi, in The Solar System, Vol. III, Planets and Satellites, G. P. Kuiper and B. M. Middlehurst, eds. (Univ. Chicago Press, Chicago, Ill.): 568.

Dollfus, A., 1971a. Diameter measurements of asteroids, in Physical Studies of Minor Planets, NASA SP 267, T. Gehrels, ed. (Govt. Printing Office, Washington, D.C.): 25.

Dollfus, A., 1971b. Physical studies of asteroids by polarization of the light, in Physical Studies of Minor Planets, NASA SP-267, T. Gehrels, ed. (Govt. Printing Office, Washington, D.C.): 95.

Drickamer, H. G., 1965. The effect of high pressure on the electronic structure of solids, in Solid State Physics, Vol. 17, F. Seitz and D. Turnbull, eds. (Academic Press, New York): 1.

Drobyshevskii, E. M., 1964. The volt-ampere characteristics of a homopolar cell, Soviet Physics- Technical Physics 8: 903.

Duke, M. B., and L. T. Silver, 1967. Petrology of eucrites, howardites and mesosiderites, Geochim. et Cosmochim. Acta 31: 1637.

Dyce, R. B., and G. H. Pettengill, 1967. Radar determination of the rotations of Venus and Mercury, Astron. J. 72: 351.

Eberhardt, P., J. Geiss and N. Grogler, 1965. Uber die Verteilung der Uredelgase im Meteoriten Khor Temiki, Tschermaks Min. Petr. Mitt. 10:535.

von Eckermann, H., 1948. The alkaline district of Alno Island, Sverig. Geol. Undersdk. Ser. Ca. 36.

von Eckermann, H., 1958. The alkaline and carbonatitic dikes of the Alno formation on the mainland northwest of Alno Island, Kungl. Vetenskaps Akademiens Handl., Fjarde serien 7(2).

Elsasser, W. M., 1963. Early history of the Earth, in Earth Science and Meteoritics, J. Geiss and E. D. Goldberg, eds. (North-Holland Publ. Co., Amsterdam, Holland): 1.

von Engel, A., 1955. Ionized Gases (Oxford Univ. Press, London).

Engel, A. E. J., B. Nagy, L. A. Nagy, C. G. Engel, G. O. W. Kremp and C. M. Drew, 1968. Alga-like forms in Onverwacht Series, South Africa: oldest recognized lifelike forms on Earth, Science 161: 1005.

Ephemerides of Minor Planets for 1969 (Institute of Theoretical As. tronomy, Acad. Sci. USSR. Publication "Nauka" Leningrad Department, Leningrad, 1968), published annually.

Epstein, S. and H. P. Taylor, Jr., 1970. The concentration and isotopic composition of hydrogen, carbon and silicon in Apollo 11 1unar rocks and minerals, in Proc. Apollo 11 Lunar Science Conf., Vol. 2, A. A. Levinson, ed. (Pergamon Press, New York): 1085.

Epstein, S., and H. P. Taylor, Jr., 1972. $0^{18}/0^{16}$, Si^{30}/Si^{28}, C^{13}/C^{12}, and D/H studies of Apollo 14 and 15 samples, in Lunar Science III, C. Watkins, ed. (The Lunar Science Institute, Houston, Tx.): 236.

Eucken, A., 1944a. Uber den Zustand des Erdinnern, Naturwiss Heft 14/26:112.

Eucken, A., 1944b. Physikalisch-chemische Betrachtungen uber die fruheste Entwicklungsgeschichte der Erde, Nachr. Akad. Wiss. in Gottingen, Math.-Phys. Kl., Heft 1: 1.

Everhart, E., 1969. Close encounters of comets and planets, Astron. J. 74 735.

Everhart, E., 1972. The origin of short-period comets, Astrophys. Lett 10:131.

Everhart, E., 1974. Paper presented at IAU Coll. No. 25, Goddard Space Flight Center, Greenbelt, Md., in Oct. 1974.

Fahleson, U., 1973. Plasma-vehicle interactions in space. Some aspects on present knowledge and future developments, in Photon and particle Interactions with Surfaces in Space, R. J. L. Grard, ed. (Reidel Dordrecht, Holland): 563.

Falthammar, C.-G., 1974. Laboratory experiments of magnetospheric interest, Space Sci. Rev. 15(6): 803.
Fanale, F. P., 1971. A case for catastrophic early degassing of the Earth, Chem. Geol. 8: 79.

Fireman, E. L., 1958. Distribution of helium-3 in the Carbo meteorite, Nature 181:1725.

Fleischer, R. L., P. B. Price, R. M. Walker, M. Maurette and G. Morgan, 1967a. Tracks of heavy primary cosmic rays in meteorites, J. Geophys. Res. 72:355.

Fleischer, R. L., P. B. Price, R. M. Walker and M. Maurette, 1967b. Origins of fossil charged-particle tracks in meteorites, J. Geophys. Res. 72:331.

Fodor, R. V., and K. Keil, 1973. Composition and origin of lithic fragments in L- and H-group chondrites, Meteoritics 8: 366.

Fowler, W. A., 1972. What cooks with solar neutrinos?, Nature 238: 24.

Franklin, F. A., and G. Colombo, 1970. A dynamical model for the radical structure of Saturn's rings, Icarus 12: 338.

Fredriksson, K., and P. De Carli, 1964. Shoek emplaced argon in a stony meteorite, J. Geophys. Res. 69: 1403.

Fredriksson, K., A. Noonan and J. Nelen, 1973. Meteoritie, lunar and Lonar impact chondrules, The Moon 7: 475.

Freeman, J. W., Jr., M. A. Fenner, R. A. Lindeman, R. Medrano and J. Meister, 1972. Suprathermal ions near the Moon, Icarus 16: 328.

French, B., and N. Short, 1968. Shock Metamorphism of Natural Meteorites (Mono Book Corp., Baltimore, Md.).

Fuchs, L. H., 1971. Occurrenee of wollastonite, rhonite and andradite in the Allende meteorite, Amer. Miner 56: 2053.

Fuller, M., 1974. Lunar magnetism, Rev. Geophys. Space Phys. 12: 23.

Ganapathy, R., J. C. Laul, J. W. Morgan and E. Anders, 1971. Glazed lunar rocks: origin by impact, Science 172: 556.

Gast, P. W., 1971. The chemical composition of the Earth, the Moon, and chondritic meteorites, in The Nature of the Solid Earth, E. C. Robertson, ed. (McGraw-Hill, New York): 19.

Gast, P. W., 1972. The chemical composition and structure of the Moon, The Moon 5: 121.

Gault, D. E., and E. D. Heitowit, 1963. The partition of energy for hypervelocity impact craters formed in rock, in Sixth Symposium on Hypervelocity Impact, Vol. 2: 419.

Gault, D. E., E. M. Shoemaker and H. J. Moore, 1963. Spray Ejected from the Lunar Surface by Meteoroid Impact, NASA Tech. Note No. D-1767 (Govt. Printing Office, Washington, D.C.).

Gault, D. E., W. L. Quaide and V. R. Oberbeck, 1968. Impact cratering mechanics and structures, in Shock Metamorphism of Natural Materials, B. M. French and N. M. Short, eds. (Mono Book Corp., Baltimore, Md.): 87.

Gehrels, T., ed., 1971. Physical Studies of Minor Planets, NASA SP-267 (Govt. Printing Office, Washington, D.C.).

Gehrels, T., 1972a. Physical parameters of asteroids and interrelations with comets, in From Plasma to Planet, A. Elvius, ed. (Wiley, New York): 169.

Gehrels, T., 1972b. Paper presented at the Coll. on Toro, Tucson, Arizona, Dec., 1972.

Geiss, J., and H. Reeves, 1972. Cosmic and solar system abundances of deuterium and helium-3, Astron. Astrophys. 18: 126.

Gerstenkorn, H., 1955. Uber Gezeitenreibung beim Zweikorperproblem, Z. Astrophys. 36: 245.

Gerstenkorn, H., 1968. A reply to Goldreich, Icarus 9: 394.

Gerstenkorn, H., 1969. The earliest past of the Earth-Moon system, Icarus 11:189.

Gibson, E. K., and S. M. Johnson, 1971. Thermal analysis- inorganic gas release studies of lunar samples, in Proc. Second Lunar Science Conf., Vol. 2, A. A. Levinson, ed. (MIT Press, Cambridge, Mass.), 1351.

Gibson, E. K., and S. M. Johnson, 1972. Thermogravimetric-quadrupole mass-spectrometric analysis of geochemical samples, Thermochim. Acta 4: 49.

Gibson, E. K., and G. W. Moore, 1973. Volatile-rich lunar soil: evidence of possible cometary impact, Science 179: 69.

Giuli, R. T., 1968a. On the rotation of the Earth produced by gravitational accretion of particles, Icarus 8: 301.

Giuli, R. T., 1968b. Gravitational accretion of small masses attracted from large distances as a mechanism for planetary rotation, Icarus 9: 186.

Goldreich, P., 1965. An explanation of the frequent occurrence of eommensurable motions in the solar system. Mon. Not. Roy. Astron. Soc. 130(3): 159.

Goldreieh, P., 1968. On the controversy over the effcet of tidal friction upon the history of the Earth-Moon system. A reply to comments by H. Gerstenkorn, Icarus 9: 391.

Goldreich, P., and S. Peale, 1966. Spin-orbit coupling in the solar system, Astron. J. 71:425.

Goldreich, P., and S. Peale, 1967. Spin-orbit coupling in the solar system II. The resonant rotation of Venus, Astron. J. 72: 662.

Goldreich, P., and S. J. Peale, 1968. The dynamics of planetary rotations, Ann. Rev. Astron. Astrophys. 6: 287.

Goldreich, P., and S. Soter, 1966. Q in the solar system, Icarus 5: 375.

Gollnow, H., 1962. A search for magnetic stars, Publ. Astron. Soc. Pac. 74:163.

Gopalan, K., and G. W. Wetherill, 1969. Rubidium-strontium age of ampho terite (LL) chondrites, J. Geophys. Res. 74: 4349.
Greenstein, J. L., and C. Arpigny, 1962. The visual region of the spectrum of comet Mrkos (1957d) at high resolution, Astrophys. J. 135: 892.

Grevesse, N., G. Blanquet and A. Boury, 1968. Abondances solaires de quelques elements representatifs au point de vue de la nucleo-synthese, in Origin and Distribution of the Elements, L. H. Ahrens, ed. (Pergamon, New York): 177.

Grossman, L., and J. Larimer, 1974. Early chemical history of the solar system, Rev. Geophys. Space Phys. 12: 71.

ter Haar, D., 1948. Studies on the origin of the solar system, Det Kgl. Danske Videnskabs Selskab Mat.-Fys. Meddelelser, Kobenhavn 25(3).

ter Haar, D., 1949. Stellar rotation and age, Astrophys. J. 110: 321.

ter Haar, D., 1967. On the origin of the solar system, Ann. Rev. Astron. Astrophys. 5: 267.

Haerendel, G., and R. Lust, 1970. Electric fields in the ionosphere and magnetosphere. in Particles and Fields in the Magnetosphere, B. M. McCormac, ed. (D. Reidel Publ. Co., Dordrecht, Holland): 213.

Hagihara, T., 1961, The stability of the solar system, in The Solar System, Vol. III, Planets and Satellites, B. M. Middlehurst and G. P. Kuiper, eds. (Univ. Chicago Press, Chicago, Ill.): 95.

Halliday, I., 1969. Comments on the mean density of Pluto, Pub. Astron. Soc. Pac. 81: 285.

Hamid, S., B. G. Marsden and F. L. Whipple, 1968. Influence of a comet belt beyond Neptune on the motions of periodic comets, Astron. J. 73: 727.

Hanks, T. C., and D. L. Anderson, 1969. The early thermal history of the Earth, Phys. Earth Planet. Inter. 2(1): 19.

Hapke, B. W., A. J. Cohen, W. A. Cassidy and E. N. Wells, 1970. Solar radiation effects on the optical properties of Apollo 11 samples, in Proc. Apollo 11 Lunar Science Conf., Vol. 3, A. A. Levinson, ed. (Pergamon Press, New York): 2199.

Harris, P. G., and D. C. Tozer, 1967. Fractionation of iron in the solar system, Nature 215: 1449.

Harteck, P., and J. H. D. Jensen, 1948. Uber den Sauerstoffgehalt der Atmosphare, Z. Naturforsch. 3a: 591.

Hassan, H. A., 1966. Characteristics of a rotating plasma, Phys. Fluids 9: 2077.

Herczeg, T., 1968. Planetary cosmogonies, in Vistas in Astronomy, Vol. 11, A. Beer, ed. (Pergamon Press, London): 175.

Heymann, D., 1967. On the origin of hypersthene chondrites: ages and shock effects of black chondrites, Icarus 6: 189.

Hirayama, K., 1918. Researches on the distribution of the mean motion of asteroids, J. Coll. Sci. Imp. Univ. Tokyo 41: article 3.

Hirschberg, J., 1973. Helium abundance of the Sun, Rev. Geophys. Space Phys. 11:115.

Hohenberg, C. M., and J. H. Reynolds, 1969. Preservation of the iodinexenon record in meteorites, J. Geophys. Res. 74: 6679.

Holland, H. O., 1964. On the chemical evolution of the terrestrial and cytherean atmospheres, in The Origin and Evolution of Atmospheres and Oceans, P. J. Brancazio and A. G. W. Cameron, eds. (Wiley, New York): 86.

Honda, M., and J. R. Arnold, 1967. Effects of cosmic rays on meteorites, in Handb. Physik, Vol. 46/2, (Springer-Verlag, Berlin-Heidelberg): 613.

van Houten, C. J., I. van Houten-Groeneveld, P. Herget and T. Gehrels, 1970. The Palomar-Leiden survey of faint minor planets, Astron. Astrophys. Supp. Ser. 2:339.

Howard, H. T., G. L. Tyler, G. Fjeldbo, A. J. Kliore, G. S. Levy, D. L. Brunn, R. Dickinson, R. E. Edelson, W. L. Martin, R. B. Postal, B. Seidel, T. T. Sesplaukis, D. L. Shirley, C. T. Stelzried, D. N. Sweetnam, A. I. Zygielbaum, P. B. Esposito, J. D. Anderson, I. I. Shapiro and R. D. Reasenberg, 1974. Venus: Mass, gravity, field, atmosphere and ionosphere as measured by the Mariner 10 dual-frequency radio system, Science 183: 1297.

Hoyle, F., 1960. On the origin of the solar nebula, Quart. J. Roy. Astron. Soc. 1: 28.

Hoyle, F., 1963. Formation of the planets, in Origin of the Solar System, R. Jastrow and A. G. W. Cameron, eds. (Academic Press, New York): 63.

Hoyle, F., and N. C. Wickramasinghe, 1968. Condensation of the planets, Nature 217:415.

Hubbard, W. B., 1969. Thermal models of Jupiter and Saturn, Astrophys. J. 155: 333

Ip, W.-H., 1974a. Studies of Small Bodies in the Solar System, Ph.D. Thesis, Univ. of Calif., San Diego, California.

Ip, W. -H. , 1 9 74b. Personal communication.

Ip, W.-H., 1974c. Planetary accretions in jet streams, Astrophys. Space Sci. 31:57.

Ip, W.-H., and R. Mehra, 1973. Resonances and librations of some Apollo and Amor asteroids with the Earth, Astron. J. 78: 142.

Ip, W., and A. Mendis, 1974. On the effect of accretion and fragmentation in interplanetary matter streams, Astrophys. Space Sci. 30: 233.

Janiczek, P. M., P. K. Seidelmann and R. L. Duncombe, 1972. Resonances and encounters in the inner solar system, Astron. J. 77: 764.

Jedwab, J., 1967. La magnetite en plaquettes des meteorites carbonees d'Alais, Ivuna et Orgueil, Earth Planet. Sci. Lett. 2: 440.

Jefferys, W. H., 1967. Nongravitational forces and resonances in the solar system, Astron. J. 72: 872.
Jeffreys, H., 1962. The Earth; Its Origin, History and Physical Constitution, 4th ed.

(Cambridge Univ. Press, Cambridge, England).

Johnson, T. V., and F. P. Fanale, 1973. Optical properties of carbonaceous chondrites and their relationship to asteroids, J. Geophys. Res. 78: 8507.

Jokipii, J. R., 1964. The distribution of gases in the protoplanetary nebula, Icarus 3: 248.

Joss, P. C., 1972. Unpublished preprint.

Kaula, W. M., 1968. An Introduction to Planetary Physics; The Terrestrial Planets (Wiley, New York).

Kaula, W. M., 1971. Dynamical aspects of lunar origin, Rev. Geophys. Space Phys. 9: 217.

Kaula, W. M., 1974. Mechanical] processes affecting differentiation of proto-lunar material, in The Soviet-American Conference on Cosmochemistry of the Moon and Planets, NASA SP-370 (U.S. Govt. Printing Office, Washington, D.C.). To be published 1976.

Kaula, W. M., and A. W. Harris, 1973. Dynamically plausible hypotheses of lunar origin, Nature 245: 367.

Kelley, M. C., F. S. Mozer and U. V. Fahleson, 1971. Electric fields in nighttime and daytime auroral zone, J. Geophys. Res. 76: 6054.

Kerridge, J. F., 1970. Some observations on the nature of magnetite in the Orgueil meteorite, Earth Planet. Sci. Lett. 9: 299.

Kerridge, J. F., and J. F. Vedder, 1972. Accretionary processes in the early solar system: an experimental approach, Science 177: 161.

Kiang, T., 1966. Bias-free statistics of orbital elements of asteroids, Icarus 5:437.

Kinard, W. H., R. L. O'Neal, J. M. Alvarez and D. H. Humes, 1974. Interplanetary and near-Jupiter meteoroid environments: preliminary results from the meteoroid detection experiment, Science 183: 321.

Kirsten, T. A., and O. A. Schaeffer, 1971. High energy interactions in space, in Elementary Particles Science Technology and Society, L. C. L. Yuan, ed. (Academic Press, New York): 76.

Kopal, Z., 1966. On the possible origin of the lunar maria, Nature 210: 188.

Kopal, Z;, 1973. The Solar System (Oxford Univ. Press, New York).

Kresak, L., 1968. Structure and evolution of meteor streams, in Physics and Dynamics of Meteors, L. Kresak and P. Millman, eds. (D. Reidel, Dordrecht, Holland): 391.

Kuiper, G. P., 1951. On the origin of the solar system, in Astrophysics, J. A. Hynek, ed. (McGraw-Hill, New York): 404.

Kuiper, G. P., 1957. Further studies on the origin of Pluto, Astrophys. J. 125:287.

Kumar, S. S., 1972. On the formation of Jupiter, Astrophys. Space Sci. 16:52.

Lal, D., 1972a. Accretion processes leading to formation of meteorite parent bodies, in From Plasma to Planet, A. Elvius, ed. (Wiley, New York): 49.

Lal, D., 1972b. A "cometary" suggestion, in From Plasma to Planet, A. Elvius, ed. (Wiley, New York): 349.

Lehnert, B., 1966. Ionization process of a plasma, Phys. Fluids 9: 774.

Lehnert, B., 1967a. Experimental evidence of plasma instabilities, Plasma Phys. 9: 301.

Lehnert, B., 1967b. Space-charge effects by nonthermal ions in a magnetized plasma, Phys. Fluids 10: 2216.

Lehnert, B., 1970a. On the conditions for cosmic grain formation, Cosmic Electrodyn. 1: 219.

Lehnert, B., 1970b. Minimum temperature and power effect of cosmical plasmas interacting with neutral gas, Cosmic Electrodyn. 1: 397.

Lehnert, B., 1971. Rotating plasmas, Nucl. Fus. 11: 485.

Levin, B. J., 1972. Origin of the Earth, in The Upper Mantle, A. R. Ritsema, ed., Tectonophysics 13: 7.

Levin, B. J., and V. S. Safronov, 1960. Some statistical problems concerning the accumulation of planets, Theor. Probab. Appl. 5: 220.

Lewis, J. S., 1971a. Consequences of the presence of sulfur in the core of the Earth, Earth Planet. Sci. Lett. 11: 130.

Lewis, J. S., 1971b. Satellites of the outer planets: their physical and chemical nature, Icarus 15: 174.

Lin, S.-C., 1961. Limiting velocity for a rotating plasma, Phys. Fluids 4: 1277.

Lin, S.-C., 1966. Cometary impact and the origin of tektites, J. Geophys. Res. 71: 2427.

Lindberg, L., and C. T. Jacobsen, 1964. Studies of plasma expelled from a coaxial plasma gun, Phys. Fluids Supp. S44: 844.

Lindberg, L., and L. Kristoferson, 1971. Reverse deflection and contraction of a plasma beam moving along curved magnetic field lines, Cosmic Electrodyn. 2:305.

Lindberg, L., E. Witalis and C. T. Jacobsen, 1960. Experiments with plasma rings, Nature 185:452.

Lindblad, B. A., 1935. A condensation theory of meteoritic matter and its cosmological sign)ficance, Nature 135: 133.

Lindblad, B. A., and R. B. Southworth, 1971. A study of asteroid families and streams by computer techniques, in Physical Studies of Minor Planets, NASA SP-267, T. Gehrels, ed. (Govt. Printing Offfice, Washington, D.C.): 337.

Lodochnikov, V. N., 1939. Some general problems connected with magma producing basaltic rocks, Zap. Mineral. O-om 64: 207.

Lovell, A. C. B., 1954. Meteor Astronomy (Oxford Univ. Press, London).
Lundquist, S., 1951. On the stability of magneto-hydrostatic fields. Phys. Rev. 83:307.

Lust, R., and A. Schluter, 1955. Angular momentum transport by magnetic fields and the braking of rotating stars, Z. Astrophys. 38: 190.

Lyttleton, R. A., 1936. On the possible results of an encounter of Pluto with the Neptunian system, Mon. Not. Roy. Astron. Soc. 97: 108.

Lyttleton, R. A., 1953. The Comets and Their Origin (Cambridge Univ. Press, Cambridge, England).

Lyttleton, R. A., 1968. On the distribution of major axes of long-period comets, Mon. Not. Roy. Astron. Soc. 139: 225.

Lyttleton, R. A., 1969. On the internal structures of Mercury and Venus, Astrophys. Space Sci. 5: 18.

Maas, R. W., E. P. Ney and N. J. Woolf, 1970. The 10 micron emission peak of Comet Bennett 1969i, Astrophys. J., Part 2 161: L101.

McCord, T. B., 1966. Dynamical evolution of the Neptunian system, Astron. J. 71: 585.

McCord, T. B., J. B. Adams and T. V. Johnson, 1970. Asteroid Vesta: spectral reflectivity and compositional implications, Science 168: 1445.

McCrea, W. H., 1960. The origin of the solar system, Proc. Roy. Soc. London 256: 245.

McCrosky, R. E., 1970. Fireballs and the physical theory of meteors, Bull. Astron. Inst. Czechosl. 21: 271.

MacDonald, G. J. F., 1966. Origin of the Moon; dynamical considerations, in The Earth-Moon System, B. G. Marsden and A. G. W. Cameron, eds. (Plenum Press, New York): 165.

Macdougall, D., B. Martinek and G. Arrhenius, 1972. Regolith dynamics, in Lunar Science III, C. Watkins, ed. (The Lunar Science Institute, Houston, Tx.): 498.

Macdougall, D., R. S. Rajan and P. B. Price, 1974. Gas-rich meteorites: possible evidence for origin on a regolith, Science 183: 73.

McQueen, R. L., and S. P. Marsh, 1960. Equations of state for nineteen metallic elements from shock-wave measurements to two megabars, J. Appl. Phys. 31:1253.

Majeva, S. V., 1971. Thermal history of the Earth with iron core, Izv. Akad. Nauk SSSR, Fiz. Zemli, No. 1:3. Eng. trans., Physics Solid Earth 1971: 1.

Malmfors, K. G., 1945. Determination of orbits in the field of a magnetic dipole with applications to the theory of the diurnal variation of cosmic radiation, Ark. f. Mat. Astr. Fys. 32A(8)

Manka, R. H., F. C. Michael, J. W. Freeman, P. Deal, C. W. Par kin, D. S. Colburn and C. P. Sonett, 1972. Evidence for acceleration of lunar ions, in Lunar Science III, C. Watkins, ed., (The Lunar Science Institute, Houston, Tx.): 504.

Marcus, A. H., 1967. Formation of the planets by the accretion of planetesimals: some statistical problems, Icarus 7: 283.

Marsden, B. G., 1968. Comets and non-gravitational forces, Astron. J. 73:367.

Marsden, B. G., 1970. On the relationship between comets and minor planets, Astron. J. 75: 206.

Marti, K., 1973. Ages of the Allende chondrules and inclusions, Meteoritics 8:55.

Martin, R. F., and G. Donnay, 1972. Hydroxyl in the mantle, Amer. Mineralogist 57: 554.

Mason, B., ed., 1971. Handbook of Elemental Abundances in Meteorites (Gordon and Breach Sci. Publ., New York).

Mendis, A., 1973. Comet-meteor stream complex, Astrophys. Space Sci. 20:165.

Meyer, C., Jr., 1969. Sputter Condensation of Silicates. Ph.D. thesis, Scripps Institution of Oceanography, Univ. of Calif., San Diego, California.

Meyer, C., Jr., 1971. An experimental approach to circumstellar condensation, Geochim. Cosmochim. Acta 35: 551.

Millman, P. M., 1972. Cometary meteoroids, in From Plasma to Planet, A. Elvius, ed. (Wiley, New York): 157.

Morrison, D., 1973. New techniques for determining sizes of satellites and asteroids, Comments on Astrophys. Space Phys. 5: 51.

Morrison, D., 1974. Albedos and densities of the inner satellites of Saturn, Icarus 22: 51.

Moulton, F. R., 1905. Report of F. R. Moulton, Carnegie Institution Yearbook No. 4 (Carnegie Inst., Tech., Pittsburgh, Penn.): 186.

Mozer, F. S., and U. V. Fahleson, 1970. Parallel and perpendicular electric fields in an aurora, Planet. Space Sci. 18: 1563.

Mrkos, A., 1972. Observation and feature variations of comet 1969e before and during the perihelion passage, in From Planet to Plasma, A. Elvius, ed. (Wiley, New York): 261.

Muller, E. A., 1968. The solar abundances, in Origin and Distribution of the Elements, L. H. Ahrens, ed., (Pergamon, New York): 155.

Muller, P. M., and W. L. Sjogren, 1969. Lunar gravimetry and mascons, Appl. Mech. Rev. 22: 955.

Munk, W. H., 1968. Once again-tidal friction, Quart. J. Roy. Astron. Soc. 9:352.

Munk, W., and G. J. F. MacDonald, 1960. The Rotation of the Earth; a Geophysical Discussion (Cambridge Univ. Press, Cambridge, England).

Murphy, R. E., D. P. Cruikshank and D. Morrison, 1972. Radii, albedos, and 20-micron brightness temperatures of lapetus and Rhea, Astrophys. J., Part 2 177: L93.
Murthy, V. R., and H. T. Hall, 1970. On the possible presence of sulfur in the Earth's core, Phys. Earth Planet. Inter. 2: 276.

Murthy, V. R., N. M. Evensen, B. Jahn and M. R. Coscio, Jr., 1971. Rb-Sr ages and elemental abundances of K, Rb, Sr and Ba in samples from the Ocean of Storms, Geochim. Cosmochim. Acta 35: 1139.

The Nautical Almanac, issued annually by the Nautical Almanac Office (Govt. Printing Office, Washington, D.C.).

Neugebauer, G., E. Becklin and A. R. Hyland, 1971. Infrared sources of radiation, Ann. Rev. Astron. Astrophys. 9: 67.

Neukum, G., A. Mehl, H. Fechtig and J. Zahringer, 1970. Impact phenomena of micrometeorites on lunar surface material, Earth Planet. Sci. Lett. 8:31.

Neuvonen, K. J., B. Ohlson, H. Papunen, T. A. Hakli and P. Ramdohr, 1972. The Havero ureilite, Meteoritics 7: 515 and subsequent articles.

Newburn, R. L., Jr., and S. Gulkis, 1973. A survey of the outer planets Jupiter, Saturn, Uranus, Neptune, Pluto, and their satellites, Space Sci. Rev. 3: 179.

Newton, H. A., 1891. On the capture of comets by planets, especially their capture by Jupiter, Mem. Nat. Acad. Sci. 6: 7.

Nieto, M. M., 1972. The Titius-Bode Law of Planetary Distances (Pergamon Press, New

York).

Nordenskiold, A. E., 1883. Studier och Forskningar (Centraltryckeriet, Stockholm).

Ohyabu, N., and N. Kawashima, 1972. Neutral point discharge experiment, J. Phys. Soc. Japan 33:496.

Oort, J. H., 1963. Empirical data on the origin of comets, in The Solar System, Vol. IV, The Moon, Meteorites and Comets, B. M. Middlehurst and G. P. Kuiper, eds. (Univ. Chicago Press, Chicago, Ill.): 665.

Opik, E. J., 1961. The survival of comets and cometary material, Astron. J. 66:381.

Opik, E. J., 1962. Jupiter: chemical composition, structure and origin of a giant planet, Icarus 1: 200.

Opik, E. J., 1963. The stray bodies in the solar system. Part I, Survival of cometary nuclei and the asteroids, Advan. Astron. Astrophys. 2: 219.

Opik, E. J., 1966. The dynamical aspects of the origin of comets, in Nature et Origine des Cometes, Mem. Soc. R. Sci. Liege 12: 523.

Opik, E. J., 1972. Comments on lunar origin, Irish Astron. J. 10: 190.

Orowan, E., 1969. Density of the Moon and nucleation of planets, Nature 222:867.

Papanastassiou, D. A., and G. J. Wasserburg, 1969. Initial strontium isotopic abundances and the resolution of small time differences in the formation of planetary objects, Earth Planet. Sci. Lett. 5: 361.

Papanastassiou, D. A., and G. J. Wasserburg, 1971a. Lunar chronology and evolution from Rb-Sr studies of Apollo 11 and 12 samples, Earth Planet. Sci. Lett. 11:37.

Papanastassiou, D. A., and G. J. Wasserburg, 197]b. Rb-Sr ages of igneous rocks from the Apollo 14 mission and the age of the Fra Mauro formation, Earth P]anet. Sci. Lett. 12:36.

Papanastassiou, D. A., C. M. Gray and G. J. Wasserburg, 1973. The identification of early solar condensates in the Allende meteorite, Meteoritics 8:417.

Pellas, P., 1972. Irradiation history of grain aggregates in ordinary chondrites. Possible clues to the advanced stages of accretion, in From Plasma to Planet, A. Elvius, ed.

(Wiley, New York): 65.

Persson, H., 1963. Electric field along a magnetic line of force in a lowdensity plasma, Phys. Fluids 6: 1756.

Persson, H., 1966. Electric field parallel to the magnetic field in a low-density plasma, Phys. Fluids 9: 1090.

Petschek, H. E., 1960. Comment following Alfvén, H., Collision between a nonionized gas and a magnetized plasma, Rev. Mod. Phys. 32: 710.

Piotrowski, S., 1953. The collisions of asteroids, Acta Astron. Ser. A5: 115.

Podgorny, I. M., and R. Z. Sagdeev, 1970. Physics of interplanetary plasma and laboratory experiments, Soviet Phys. Usp. 12: 445.

Podosek, F. A., 1970. Dating of meteorites by the high-temperature release of iodine-correlated Xe^{129}, Geochim. Cosmochim. Acta 34: 341.

Porter, J. G., 1961. Catalogue of cometary orbits, Mem. Brit. Astron. Ass. 39(3): 1.

Porter, J. G., 1963. The statistics of comet orbits, in The Solar System, Vol. IV, The Moon, Meteorites and Comets, B. M. Middlehurst and G. P. Kuiper, eds. (Univ. Chicago Press, Chicago, Ill.): 550.

Price, P. B., 1973. A cosmochemical view of cosmic rays and solar particles, Space Sci. Rev. 15:69.

Price, P. B., R. S. Rajan, I. D. Hutcheon, D. Macdougall and E. K. Shirk, 1973. Solar flares, past and present (abst.), in Lunar Science IV, J. W. Chamberlain and C. Watkins, eds. (The Lunar Science Institute, Houston, Tx.): 600.

Rabe, E., 1957a. On the origin of Pluto and the masses of the protoplanets, Astrophys. J. 125:290.

Rabe, E., 1957b. Further studies on the orbital development of Pluto, Astrophys. J. 126: 240.

Ramsey, W. H., 1948. On the constitution of the terrestrial planets, Mon. Not. Roy. Astron. Soc. 108:406.

Ramsey, W. H., 1949. On the nature of the Earth's core, Mon. Not. Roy. Astron. Soc., Geophys. Suppl. 5:409.

Rasool, S. I., and C. De Bergh, 1970. The runaway greenhouse and the accumulation of CO_2 in the Venus atmosphere, Nature 226: 1037.

Reid, A. M., and K. Fredriksson, 1967. Chondrules and chondrites, in Researches in Geochemistry, Vol. 2, P. H. Abelson, ed. (John Wiley, New York), 170.

Reynolds, R. T., and A. L. Summers, 1965. Models of Uranus and Neptune, J. Geophys. Res. 70: 199.

Richter, N. B., 1963. The Nature of Comets (Metheun, London).

Ringwood, A. E., 1959. On the chemical evolution and densities of the planets, Geochim. Cosmochim. Acta 15: 257.

Ringwood, A. E., 1966. Chemical evolution of the terrestrial planets, Geochim. Cosmochim. Acta 30: 41.

Roach, J. R., 1975. Counterglow from the Earth-Moon libration points, Planet. Space Sci. 23: 173.

Roy, A. E., and M. W. Ovenden, 1954. On the occurrence of commensurable mean motions in the solar system, Mon. Not. Roy. Astron. Soc. 114: 232.

Safronov, V. S., 1954. On the growth of planets in the protoplanetary cloud, Astron. Zh. 31:499.

Safronov, V. S., 1958, The growth of terrestrial planets, Vopr. Kosmog. 6:63.

Safronov, V. S., 1960. Accumulation of planets of the earth's group, Vopr. Kosmog. Akad. Nauk SSSR 7:59.

Safronov, V. S., 1969. Evolution of the preplanetary cloud and the formation of the earth and planets (Nauka, Moscow) (in Russian).

Safronov, V. S., and E. V. Zvjagina, 1969. Relative sizes of the largest bodies during the accumulation of planets, Icarus 10: 109.

Samara, G. A., 1967. Insulator-to-metal transition at high pressure, J. Geophys. Res. 72: 671.

Schindler, K., 1969. Laboratory experiments related to the solar wind and the magnetosphere, Rev. Geophys. 7: 51.

Schmidt, O. Yu, 1944. Meteoritic theory of the origin of the Earth and planets, Dokl. Akad. Nauk SSSR 45(6): 245.

Schmidt, O. Yu, 1945. Astronomical age of the Earth, Dokl. Akad. Nauk SSSR 46(9): 392.

Schmidt, O. Yu, 1946a. On the law of planetary distances, Comptes Rendus (Doklady) de l'Academie des Sciences de l' USSR 52: 8.

Schmidt, O. Yu, 1946b. A new theory on the origin of the Earth, Priroda No. 7: 6.

Schmidt, O. Yu, 1947. A new theory on the origin of the Earth and planets, Trans. All-Union Geog. Soc. No. 3: 265.

Schmidt, O. Yu, 1959. A Theory of the Origin of the Earth; Four Lectures, G. H. Hanna, trans. (Lawrence and Wishart, London): 139.

Schubart, J., 1968. Long-period effects in the motion of Hilda-type planets, As tron . J. 73: 99.

Schubart, J., 1971. Asteroid masses and densities, in Physical Studies of Minor Planets, NASA SP 267, T. Gehrels, ed. (Govt. Printing Office, Washington, D.C.): 33.

Schweizer, F., 1969. Resonant asteroids in the Kirkwood gaps and statistical explanations of the gaps, Astron. J. 74: 779.

Seidelmann, P. K., W. J. Klepczynski, R. L. Duncombe and E. S. Jackson, 1971. Determination of the mass of Pluto, Astron. J. 76: 488.

Sherman, J. C., 1969. Some Theoretical Aspects of the Interaction between a Plasma Stream and a Neutral Gas in a Magnetic Field, Report No. 69 29 (Division of Plasma Physics, Roy. Instit. of Tech., Stockholm).

Sherman, J. C. 1972. The critical velocity of gas-plasma interaction and its possible hetegonic relevance, in From Plasma to Planet, A. Elvius, ed. (Wiley, New York): 315.

Sherman, J. C., 1973. Review of the critical velocity gas-plasma interaction, part II: theory, Astrophys. Space Sci. 24: 487.

Signer, P., and H. E. Suess, 1963. Rare gases in the sun, in the atmosphere, and in meteorites, in Earth Science and Meteoritics, J. Geiss and E. D. Goldberg, eds. (North-Holland Publ. Co., Amsterdam, Holland): 241.

Simakov, G. V., M. A. Podurets and R. F. Trunin, 1973. Novye Dannye o Szhimaemosti Okislov i Ftoridov i Gipoteza ob Odnorodnom Sostave Zmeli, Dokl. Akad. Nauk SSSR 211: 1330.

Sinclair, A. T., 1969. The motions of minor planets close to commensurabilities with Jupiter, Mon. Not. Roy. Astr. Soc. 142: 289.

Singer, S. F., 1968. The origin of the moon and geophysical consequences, Geophys. J. 15: 205.

Singer, S. F., 1970. Origin of the moon by capture and its consequences, Trans. Am. Geophys. Union 51: 637.

Soberman, R. K., S. L. Neste and K. Lichtenfeld, 1974. Particle concentration in the asteroid belt from Pioneer 10, Science 183: 320.

Sockol, P. M., 1968. Analysis of a rotating plasma experiment, Phys. Fluids 11:637.

Solomon, P., and N. Woolf, 1972. Interstellar Deuterium: Chemical Fractionation, Report No. 14 (School of Phys. and Astron., Univ. Minnesota, Minneapolis, Minnesota).

Spitzer, L., 1968. Diffuse Matter in Space (Interscience, New York).

Stein, W., 1972. Circumstellar infrared emission- theoretical overview, Pub. Astron. Soc. Pac. 84: 627.

Stepflo, J. O., 1969. A mechanism for the build-up of flare energy, Solar Phys. 8: 115.
Strangway, D. W., W. A. Gose, G. W. Pearce and J. G. Carnes, 1972. Magnetism and the history of the Moon, in American Institute of Physics Conference Proceedings of Magnetism and Magnetic Materials, No 10: 1178.

Stuart-Alexander, D. E., and K. A. Howard, 1970. Lunar maria and circular basins~- a review, Icarus 12: 440.

Suess, H. E., and H. C. Urey, 1956. Abundances of the elements, Rev. of Mod. Phys. 28: 53.

Swings, P., and T. Page, 1948. The spectrum of Comet 1947n, Astrophys. J. 108:526.

Takenouchi, T., 1962. On the characteristic motion and the critical argument of asteroid (279) Thule, Ann. Tokyo Astron. Obser. 7: 191.

Taylor, R. C., 1971. Photometric observations and reductions of lightcurves of asteroids, in Physical Studies of Minor Planets, NASA SP-267, T. Gehrels, ed. (Govt. Printing Office, Washington, D.C.): 117.

Toksoz, M. N., S. C. Solomon, J. W. Minear and D. H. Johnston, 1972. Thermal evolution of the Moon, The Moon 4: 190.

Torven, S., 1972. Personal communication.

Trulsen, J., 1971. Collisional focusing of particles in space causing jet streams, in Physical Studies of Minor Planets, NASA SP 267, T. Gehrels, ed. (Govt. Printing Offfice, Washington, D.C.): 327.

Trulsen, J., 1972a. Formation of comets in meteor streams, in The Motion, Evolution of Orbirs and Origin of Comets, G. A. Chebotarev, et al., eds. (D. Reidel, Dordrecht, Holland): 487.

Trulsen, J., 1972b. Theory of jet streams, in From Plasma to Planet, A. Elvius, ed. (Wiley, New York): 179.

Turekian, K. K., and S. P. Clark, Jr., 1969. Inhomogeneous accumulation of the Earth from the primitive solar nebula, Earth Planet. Sci. Lett. 6:346.

Turner, G., J. C. Huneke, F. A. Podosek and G. J. Wasserburg, 1971. 40Ar39Ar ages and cosmic ray exposure ages of Apollo 14 samples, Earth Planet. Sci. Lett. 12:19.

Tuttle, O. F., and J. Gittens, eds., 1966. Carbonatites (Interscience, New York).

Urey, H. C., 1952. The Planets: Their Origin and Development (Yale Univ. Press, New Haven, Conn.).

Urey, H. C., 1959. The atmosphere of the planets, in Handbuch der Physik, Vol. 52 (Springer-Verlag, Berlin): 363.

Urey, H. C., 1972. Abundances of the elements, Part IV: Abundances of interstellar molecules and laboratory spectroscopy, Ann. N. Y. Acad. Sci. 194:35.

Urey, H. C., and G. J. F. Macdonald, 1971. Origin and history of the Moon, in Physics and Astronomy of the Moon, Z. Kopal, ed. (Academic Press, New York): 213.

Urey, H. C., and T. Mayeda, 1959. The metallic particles of some chondrites, Geochim. Cosmochim. Acta 17: 113.

Urey, H. C., K. Marti, J. W. Hawkins and M. K. Liu, 1971. Model history of the lunar surface, in Proc. Second Lunar Science Conf., A. A. Levinson, ed. (MIT Press, Cambridge, Mass.): 987.

Van Dorn, W. G., 1968. Tsunamis on the moon? Nature 220: 1102.

Van Dorn, W. G., 1969. Lunar maria: structure and evolution, Science 165: 693.

Van Schmus, W. R., and J. A. Wood, 1967. A chemical-petrological classification for the chondritic meteorites, Geochim. Cosmochim. Acta 31:747.

Vedder, J. F., 1972. Craters formed in mineral dust by hypervelocity microparticles, J. Geophys. Res. 77: 4304.

Verniani, F., 1967. Meteor masses and luminosity, Smithsonian Contrib. Astrophys. 10: 181.

Verniani, F., 1969. Structure and fragmentation of meteorites, Space Sci. Rev. 10:230.

Verniani, F., 1973. An analysis of the physical parameters of 5759 faint radio meteors, J. Geophys. Res. 78: 8429.

Vinogradov, A. P., 1962. Origin of the Earth's shells, Izv. Akad. Nauk SSSR, Ser. Geol. 11: 3.

Vinogradov, A. P., A. A. Yaroshevskii and N. P. Il'in, 1971. Physicochemical model of element separation in the differentiation of mantle material, Phil. Trans. Roy. Soc. London, Ser. A 268: 409.

Voshage, H., and H. Hintenberg, 1963. The cosmic-ray exposure ages of iron meteorites as derived from the isotopic composition of potassium and production rates of cosmogenic nuclides in the past, in Radioactive Dating (Ins. Atomic Energy Agency, Vienna): 367.

Vsekhsvyatsky, S. K., 1958. Physical Characteristics of Comets (Nauka, Moscow) (U. S. NASA Tech. Translation F80, 1964).

Wanke, H., 1965. Der Sonnenwind als Quelle der Uredelgase in Steinmeteoriten, Z. Naturforsch. 20A: 946.

Wanke, H., 1966. Meteoritenalter und verwandte Probleme der Kosmochemie, Fortschr. Chem. Forsch. 7: 332.

Wasserburg, G. J., D. A. Papanastassiou and H. G. Sanz, 1969. Initial strontium for a chondrite and the determination of a metamorphism or formation interval, Earth Planet. Sci. Lett. 7: 33.

Wasson, J. T., 1963. Primordial rare gases in the atmosphere of the Earth, Nature 223: 163.
Wasson, J. T., 1972. Formation of ordinary chondrites, Rev. Geophys. Space Phys. 10: 711.

von Weizsacker, C. F., 1944. Uber die Entstehung des Planetsystems, Z. Astrophys. 22:319.

Wetherill, G. W., 1968. Lunar interior: constraint on basaltic composition, Science 160:1256.

Wetherill, G. W., and J. G. Williams, 1968. Evaluation of the Apollo asteroids as sources of stone meteorites, J. Geophys. Res. 73: 635.

Whipple, F. L., 1964. Evidence for a comet belt beyond Neptune, Proc. Nat. Acad. Sci. 51:711.

Whipple, F. L., 1968. Origins of meteoritic matter, in Physics and Dynamics of Meteors, L. Kresak and P. Millman, eds. (D. Reidel, Dordrecht, Holland): 481.

Whipple, F. L., 1972. Cometary nuclei- models, in Comets Scientific Da ta and Missions, G. P. Kuiper and E. Roemer, eds. (Lunar and Planetary Laboratory, Univ. Arizona, Tucson, Arizona): 4.

Wiik, H. B., 1956. The chemical composition of some stony meteorites, Geochim. Cosmochim. Acta 9: 279.

Wilcox, J. M., 1972. Why does the Sun sometimes look like a magnetic monopole? in Comments on Modern Physics, Part C- Comments on Astrophysics and Space Physics 4: 141.

Wilkening, L., D. Lal, and A. M. Reid, 1971. The evolution of the Kapoeta howardite based on fossil track studies. Earth Planet Sci. Lett. 10:334.

Williams, J. G., and G. S. Benson, 1971. Resonances in the Neptune-Pluto System, Astron. J. 76: 167.

Williams, J. G., and G. W. Wetherill, 1973. Minor planets and related objects XIII. Long-term orbital evolution of (1685) Toro, Astron. J. 78(6): 510.

Wood, J. A., 1964. The cooling rates and parent planets of several iron meteorites, Icarus 3: 429.

Wood, J. A., 1967. The early thermal history of planets: evidence from meteorites, in Mantles of the Earth and Terrestrial Planets, S. Runcorn, ed. (Interscience, New York): 3.

Wood, J. A., 1970. Petrology of the lunar soil and geophysical implications, J. Geophys. Res. 75: 6497.

Wood, J. A., and H. E. Mitler, 1974. Origin of the Moon by a modified capture mechanism, or half a loaf is better than a whole one, in Lunar Science V (The Lunar Science Institute, Houston, Tx.): 851.

Worrall, G., and A. M. Wilson, 1972. Can astrophysical abundances be taken seriously?, Nature 236: 15.

Zahringer, J., 1966. Die Chronologie der Chondriten auf Grund von Edelgasisotopen-Analysen, Meteoritika XXVII: 25.

Zimmerman, P. D., and G. W. Wetherill, 1973. Asteroidal sources of meteorites, Science 182: 51.

Zmuda, A. J., F. T. Heuring and J. H. Martin, 1967. Dayside magnetic disturbances at 1100 kilometers in the auroral oval, J. Geophys. Res. 72:1115.

[531] SYMBOLS

The symbol index is arranged alphabetically, giving English and then Greek symbols. Astrological symbols appear immediately following the English alphabet. The final portion of the index consists of the most commonly used subscripts. The section and equation numbers appearing in the central column refer to the first use of that symbol. Where one symbol has several distinct usages, each meaning is given with a section reference. For subscripted symbols that do not appear in the main body of the symbol index, the meaning may be determined by looking up the symbol and subscript in the separate portions of the index.

A	Sec. 8.3	Apocenter
A	Sec. 6.4 Eq. (6.4.13)	Variable of substitution
a	Sec. 2.1	Length of semimajor axis
	Sec. 6.4	Point label
	Sec. 7.2	Variable of substitution
B	Sec. 5.3	Magnetic field
B_{Tp}	Sec. 19.2	The transplanetary magnetic field (the magnetic field strength in the region of space outside Pluto)
B	Sec. 6.4 Eq. (6.4.14)	Variable of substitution
b	Sec. 4.3	Point label
	Sec. 7.2	Variable of substitution
C	Sec. 2.1 Eqs. (2.1.1)-(2.1.3)	Orbital angular momentum per unit mass

C_M	Sec. 2.1	Orbital angular momentum
	Sec. 13.1, Eq. (13.1.1)	Spin angular momentum
c	Sec. 5.3	Velocity of light
	Sec. 6.4	Point label
	Sec. 7.2	Variable of substitution

D	Sec. 6.7, Eq. (6.7.4)	Net transport of guiding centers
d	Sec. 8.3	Point label
	Sec. 21.8	Distance between electrodes
E	Sec. 4.3, Eqs. (4.3.4)-(4 3 5)	Proper eccentricity
	Sec. 5.3	Electric field
	Sec. 9.3	East
E_{ion}	Sec. 21.4.3, Eq. (21.4.4)	The value of the electric field at which discharge and ionization of gas become possible
$E_{\|\|}$	Sec. 15.3	Electric field parallel to the magnetic field
e	Sec. 2.1	Eccentricity
	Sec. 5.5	2.718 (the base of the natural logarithms)
	Sec. 15.3	Charge on the electron
F	Sec. 17.2, Eq. (17.2.4)	Sum of the gravitational, centrifugal, and electromagnetic forces per unit mass
f	Sec. 3.2	Force per unit mass
f_{ap}	Sec. 6.4, Eq. (6.4.3)	Force per unit mass due to apparent attraction to the guiding center of motion
f_B	Sec. 17.2	Electromagnetic force per unit mass
f_c	Sec. 3.2, Eq. (3.2.2)	Centrifugal force per unit mass
f_G	Sec. 3.2	Force per unit mass due to gravitation
f_{per}	Sec. 6.4, Eq. (6.4.4)	Force per unit mass due to a gravitational perturbation
f_q	Sec. 5.3	Electromagnetic force per unit mass
f_t	Sec. 18.3, Eq. (18.3.2)	Tidal force per unit mass
f_Ψ	Sec. 5.5	Force per unit mass due to impinging energy flux; radiation pressure
G	Sec. 2.1	Universal gravitational constant
g	Sec. 4.3	Absolute visual magnitude
	Sec. 8.2	Acceleration due to Earth's gravitationa field
h	Sec. 2.2	Height above a specified surface
	Sec. 9.2	Height of tides on a celestial body

I	Sec. 4.3, Eqs. (4.3.6)-(4.3.7)	Proper inclination
	Sec. 15.4	Electric current
i	Sec. 2.1	Orbital inclination to the ecliptic plane
i_{eq}	Sec. 2.2	Inclination of equator to the orbital plan.
i_τ	Sec. 13.6	Inclination of spin axis to the orbital plane
K	Sec. 11.2, Eq. (11.2.3)	Constant, in cm/g
	Sec. 23.2	Constant, in units of mass
K_r	Sec. 3.3, Eq. (3.3.9)	Constant, in radians
K_z	Sec. 3.3, Eq. (3.3.17)	Constant, in radians
k	Sec. 6.8	Boltzmann's constant
L	Sec. 1.4, Eq. (15.1.1)	Critical hydromagnetic parameter
	Sec. 8.5	Lagrangian points one and two
	Sec. 16.3	Electrostatic double layer
	Fig. 16.3.1	
	Sec. 26.3 Eq. (26.3.2)	Latent heat of fusion
L_4, L_5	Sec. 20.5	Lagrangian points four and five
l	Sec. 8.2	Length of a simple pendulum or the radial distance of a secondary body describing circular motion about a primary body.
	Sec. 15.1	Length (linear extent of medium)

M	Sec. 4.1	Mass of a macroscopic body
MB	Sec. 16.4	Total mass of plasma suspended by the magnetic field at any one given time
M_{H2O}	Sec. 26.4, Eq. (26.4.2)	Mass of water released by impacting planetesimals
M_j	Sec. 12.5	Mass of a jet stream
m	Sec. 5.4	Mass of a small particle or grain
m_a	Sec. 11.2	Mass of an atom
m_e	Sec. 21.9	Mass of the electron
m_H	Sec. 11.2	Mass of the hydrogen atom
m_{per}	Sec. 6.4, Eq. (6.4.4)	Small mass introducing a perturbative gravitational force

N	Sec. 4.3	Number function
	Sec. 9.3	North
N	Sec. 6.7	Number density
n	Sec. 2.2	Index of numeration
	Sec. 3.3 Eq. (3.3.15)	The integers
O	Sec. 4.3	The center or origin of motion
P	Sec. 8.3	Pericenter
P_B	Sec. 15.1	Magnetic permeability
P_0	Sec. 4.3, Eq. (4.3-6)	Forced oscillation
p	Sec. 4.3	Albedo
p_0	Sec. 4.3, Eq. (4.3.4)	Forced oscillation
Q	Sec. 9.2	An inverse function of the angle which a tidal bulge makes with respect to the tide-producing body
	Sec. 16.3	Charge passing through a circuit during a given interval of time

Q_0	Sec. 4.3, Eq. (4.3.7)	Forced oscillation
q	Sec. 2.5	Ratio of the orbital distances of the innermost and outermost orbiting bodies in one group of secondary bodies
	Sec. 5.3	Electric charge
q_n	Sec. 2.2	Ratio of the orbital distances of adjacent secondary bodies
q_0	Sec. 4.3, Eq. (4.3.5)	Forced oscillation
R	Sec. 2.2	Radius of a solid body
R_G	Sec. 12.3, Eq. (12.3.4)	Radius of growing embryo at transition point between nongravitational accretion and gravitational accretion
R_{Ξ}	Sec. 2.2	Radius of gyration; inertial radius
r	Sec. 2.4	Orbital radius
	Sec. 3.2	Radial direction
r_B	Sec. 23.2, Eq. (23.2.2)	Distance from the central body to a point on a magnetic field line from the dipole magnetic field of that body

r_{ion}	Sec. 21.4, Eq. (21.4.1)	Ionization distance (radial distance at which infalling matter can become ionized)
r_L	Sec. 11.2, Eq. (11.2.4)	Distance from a secondary body to its interior or exterior Lagrangian points one and two
r_{min}	Sec. 23.9, Eq. (23.9.6)	Minimum value of orbital radius of condensed matter which is in orbit around the primary body
r_{MR}	Sec. 18.3	The Modified Roche Limit (the radial distance at which matter orbiting a primary body cammot accrete to form a secondary body due to the tidal force of the primary)
r_{orb}	Sec. 2.1	Radial distance from primary body to orbiting secondary body
r_{per}	Sec. 6.4, Eq. (6.4.4)	Radial distance of the perturbing mass m_{per} from the guiding center of motion of another mass.
r_R	Sec. 18.3	The Roche limit (the radial distance at which the tidal force of the primary exceeds the self-gravitational force of the secondary)
r_{rel}	Sec. 21.13.3	Orbital distance at which ionization can take place for matter falling through a corotating plasma
r_s	Sec. 17.2, Eq. (17.2.13)	Radius of the surface which is the demarcation for plasma falling in toward the central body or falling into the equatorial plane
r_{syn}	Sec. 23.9	Orbital radius of a synchronous satellite; i.e., a satellite revolving with orbital velocity equal to the rotational velocity of its primary
r_{Tp}	Sec. 19.2, Eq. (19.2.2)	The maximum radial distance at which angular momentum transfer from the Sun has ever occurred; furthest extension of the transplanetary magnetic field.
S	Sec. 6.4, Eq. (6.4.3)	Displacement from the guiding center of motion of the particle executing that motion
	Sec. 9.3	South
s	Sec. 16.3	Arc length
T	Sec. 2.1	Sidereal period of revolution
T_e	Sec. 5.5, Eq. (5.5.10)	e-folding time (the time in which the value of a given parameter changes by a factor of e (2.718))
T_{gy}	Sec. 5.4	Period of gyration

T_{gz}	Sec. 2.2	Sidereal period of revolution of a grazing satellite; i.e., a secondary body having an orbit of semimajor axis equal to the radius of the primary body
T_{ion}	Sec. 23.1	Orbital period of a body orbiting at the ionization distance r_{ion}

T_{Φ}	Sec. 4.3	Period of variation in the proper elements of asteroid orbital motion
T	Sec. 6.8	Temperature
T_e	Sec. 17.3	Electron temperature
T_i	Sec. 17.3	Ion temperature
t	Sec. 3.3	Time
t_a	Sec. 12.3	Time of accretion (time at which an accreting embryo would attain an infinite radius)
t_c	Sec. 12.6, Eq. (12.6.6)	Time of catastrophic increase of an accreting embryo
t_{es}	Sec. 2.2 Eq. (2.2.3)	"Time of escape" (the ratio of the radius of a body to its escape velocity)
t_I	Sec. 16.3, Eq. (16.3.5)	Duration of a current flow
t_{inf}	Sec. 12.4	Infall time (duration of infall of matter into the solar system)
t_j	Sec. 12.5, Eq. (12.5.8)	Time at which the small radius of a contracting jet stream would reach zero
t_{res}	Sec. 16.5	Residence time (the interval in which matter resides in the plasma state)
t_v	Sec. 6.8	Time between occurrence of collisions; inverse of collision frequency
U	Sec. 12.2, Eq. (12.2.3)	Volume of a toroidal jet stream
u	Sec. 6.8	Relative velocity; "internal velocity" of a jet stream
V	Sec. 5.4	Electrostatic potential; voltage
V_b	Sec. 21.8	Burning voltage
V_{Ion}	Sec. 15.3	Ionization voltage
v	Sec. 5.5	Velocity
v_{crit}	Sec. 15.3, Eq. (15.3.1)	Critical velocity at which an infalling atom can become ionized

	Sec. 21.8	The experimental value of relative velocity of a plasma and a gas at which increased ionization occurs.

v_{es}	Sec. 2.2, Eq. (2.2.2)	Escape velocity
v_{imp}	Sec. 12.10, Eq. (12.10.1)	Impact velocity
v_{ion}	Sec. 21.4, Eq. (21.4.1)	The value of infall velocity at which ionization of infalling matter can take place
v_m	Sec. 12.12, Eq. (12.12.1)	Velocity capable of imparting sufficient kinetic energy to melt a specified mass
v_{orb}	Sec. 2.1	Orbital velocity of secondary body
v_{rel}	Sec. 21.13, Eq. (21.13.3)	Relative velocity
W	Sec. 8.2	Energy (potential and/or kinetic)
	Sec. 9.3	West
W_m	Sec. 12.12	Energy needed to melt a specified mass
W_T	Sec. 17.3	Thermal energy
w	Sec. 9.2	Energy dissipation; power
w_T	Sec. 12.10, Eq. (12.10.2)	Thermal power per unit surface area delivered by impacting mass
X	Sec. 13.4, Eq. (13.4.3)	Variable of substitution
x	Sec. 3.2	Rectilinear coordinate lying in the horizontal plane
	Sec. 12.2	Small radius of a toroidal jet stream
x_0	Sec. 6.4	Magnitude of the x axis of the epicycle described about a guiding center
Y	Sec. 13.4, Eq. (13.4-4)	Variable of substitution
y	Sec. 3.2	Rectilinear coordinate lying in the horizontal plane
Z	Sec. 13.3, Eq. (13.3-4)	Variable of substitution

z	Sec. 3.2	Rectilinear coordinate in the axial direction
$\odot$	Sec. 2.3, Fig. 2.3.1	Sun
☿	Sec. 2.1, Table 2.1.1	Mercury

♀	Sec. 2.1, Table 2.1.1	Venus
⊕	Sec. 2.1, Table 2.1.1	Earth
☾	Sec. 2.1, Table 2.1.1	Moon
♂	Sec. 2.1, Table 2.1.1	Mars
♃	Sec. 2.1, Table 2.1.1	Jupiter
♄	Sec. 2.1, Table 2.1.1	Saturn
♅	Sec. 2.1, Table 2.1.1	Uranus
♆	Sec. 2.1, Table 2.1.1	Neptune
♇	Sec. 2.1, Table 2.1.1	Pluto
☊	Sec. 17.5	Ascending node
☋	Sec. 17.5	Descending node
α	Sec. 6.8	Dimensionless proportionality factor
	Sec. 7.2, Eq. (7.2.4)	Dimensionless constant
α_Ξ	Sec. 2.2	Ratio of radius of gyraffon to equatorial radius of body
α_Ξ^2	Sec. 2.2	Normalized moment of inertia (moment of inerffa per unit mass and unit radius squared)

β	Sec. 7.2, Eq. (7.2.5)	Dimensionless constant
Γ	Sec. 11.2	Dimensionless proportionality factor
Γ_{ion}	Sec. 21.2, Eq. (21.2.1)	Specific gravitational potential of secondary body with respect to the primary body
γ	Sec. 21.4, Eq. (21.4.2)	Value of gravitational potential at which infalling matter can become ionized
γ_B	Sec. 5.5, Eq. (5.5.4)	Dimensionless proportionality factor
Δ	Sec. 7.2, Eq. (7.2.6)	Dimensionless constant
δ	Sec. 16.5, Eq. (16.5.1)	Dimensionless proportionality factor
	Sec. 3.3	Indicating incremental change

	Sec. 6.7, Eq. (6.7.1)	Geometrical factor
	Sec. 12.10, Eq. (12.10.6)	Dimensionless proportionality factor indicating maximum in temperature profile of an accreting embryo
	Sec. 17.3	Degree of ionization
	Sec. 23.5	Dimensionless proportionality factor; the normalized distance (the ratio of the orbital radius of a body to the ionization distance for its primary body)
ϵ	Sec. 9.2	An angle
ζ	Sec. 23.1, Eqs. (23.1.4)-(23.1.5)	Dimensionless proportionality factor indicating degree of ionization of infalling matter
η	Sec. 9.3	Viscosity
Θ	Sec. 2.2	Mean density of a body
θ	Sec. 8.3	An angle
k	Sec. 8.2, Eq. (8.2.3)	Constant of integration
Λ	Sec. 3.6, Eq. (3.6.1)	Dimensionless constant

λ	Sec. 3.2	Meridional angle or latitude
μ	Sec. 16.3	Magnetic dipole moment
μ_{lm}	Sec. 16.4	Lower limit of the magnetic dipole moment such that the tangential component of the magnetic field is equal to the magnitude of the total magnetic field strength
v	Sec. 6.8	Collision frequency; number of collisions per unit time
Ξ	Sec. 13.1	Moment of inertia
ξ	Sec. 8.4, Eq. (8.4.1)	Libration angle
π	Sec. 2.1	3.1415 (ratio of the circumference to the diameter of a circle)
ρ	Sec. 6.8	Density of dispersed matter
ρ_{dst}	Sec. 2.4, Eqs. (2.4.1)-(2.4.2)	Distributed density (density of a secondary body's mass when distributed along the orbit of that secondary)
Σ	Sec. 2.1	Indicating summation

σ	Sec. 5.5	Cross section
	Sec. 6.8	Collision cross section
	Sec. 12.3, Eq. (12.3.1)	Capture cross section
σ_E	Sec. 15.1	Electrical conductivity
σ_j	Sec. 12.7	Cross section of a jet stream
τ	Sec. 2.2	Spin period of a body
Υ	Sec. 9.2, Eq. (9.2.1)	Oblateness or ellipticity of a body
Φ	Sec. 15.3	Poloidal magnetic flux
Φ_p	Sec. 4.3, Eqs. (4.3.4)-(4.3 5)	Longitude of proper perihelion
Φ_Ω	Sec. 4.3, Eqs. (4.6)-(4.7)	Longitude of proper node

ϕ	Sec. 3.2	Azimuthal angle or longitude
χ	Sec. 6.7, Eq. (6.7.5)	Constant, in number/cm^3
	Sec. 11.2, Eq. (11.2.2)	Constant, in cm K/g
χ_m	Sec. 7.2, Eq. (7.2.6)	Constant, in units of number times a variable power of mass
χ_R	Sec. 7.2, Eq. (7.2.4)	Constant, im units of number times a variable power of radius
χ_σ	Sec. 7.2, Eq. (7.2.5)	Constant, in units of number times a variable power of cross section
Ψ	Sec. 5.5	Energy flux
ψ	Sec. 8.2	An angle
Ω	Sec. 9.3	Rotational angular velocity
Ω_{es}	Sec. 13.3, Eq. (13.3.3)	Rotational escape velocity
ω	Sec. 6.4	Orbital angular velocity

Subscripts	
c	Central or primary body
sc	Secondary body

em	Embryo
gn	Grain
Lm	Limiting value
0	Initial value or parameter values for the guiding center or circular motion
K	Denoting orbital parameters for a body describing Kepler (circular) motion
A	Apocenter, aphelion, apogee, etc.
P	Pericenter, perihelion, perigee, etc.
☊	Ascending (and descending) node
x,y,z	Components in the x, y, and z directions
r, ϕ, λ	Components in the r, ϕ, and λ directions
☉, ☿, ♀, ⊕, ☾, ♂, ♃, ♄, ♅, ♆, ♇	Sun, Mercury, Venus, Earth, Moon, Mars, Jupiter, Saturn, Uraus, Neptune, Pluto

[545-599] INDEX

A cloud (see clouds (A, B, C, D))
ablation (see grain ablation)
abundances of elements, table 21.5.1
accelerated particles during hetegonic era, 16.8
accretion (see also accretional processes and models of solar system evolution)
  defined, 1.4
  general characteristics, 11.1
  formation of
    asteroids as a model of incomplete accretion, 18.7
    celestial bodies, 19.8, fig. 19.8.2, table 19.8.1
    comets compared to accretion of planets, 14.8
    embryo
      growth in jet stream, 12.3 12.6, fig. 12.6.1
      heating effects, 12.10, 12.12-12.13
      spin characteristics, 13.1-13.6
      temperature profile, 12.10
    grains
      fragmentation versus accretion, 7.1, 7.3-7.4, 11.5, 12.3, 22.7
      hydromagnetic effects on grains in plasma, 15.5
      resultant orbital and physical properties of grains, 11.7, 15.1, 15.5
      selective accretion of metallic grains, 20.5
    planets
      temperature profile, 12.11, fig. 12.11.1
      time required, 12.8-12.9, table 12.8.1, fig. 12.9.1
  in jet streams, brief summary, 22.5
    possible present-day examples
      Hilda and Trojan asteroids, Thule, 11.6
    theory
    necessary properties, 11.7
    simple model, 12.3-12.8
    limitations, 12.7
    and size spectra, 7.3

of volatile substances
compared to solid grains, 18.11
by gravitational accretion, 12.3
in jet streams, 16.7, 18.11
accretion, gravitational
general characteristics, 11.4
and embryo spin, 13.1, 13.3-13.4
Giuli's theory, 13.4-13.5
statistical
defined, 13.5
general characteristics, 13.5
and spin period and inclination, 13.6, fig. 13.6.1
transition from nongravitational accretion to gravitational accretic 7.4, 12.3
accretion, nongravitational (see also fluffy aggregates)
general characteristics, 11.5
basic difficulties and solutions, 11.5
and density waves, 14.3, 14.8, 19.3
and embryo spin, 13.2
of fluffy aggregates in space
electrically polarized grains, 7.4, figs. 7.4.1-7.4.2, 11.5, 12.3
magnetized grains, 12.3, 22.7, fig. 22.7.1
and jet streams, 11.5
transition from nongravitational accretion to gravitational accretic 12.3
accretion, runaway
definition, 11.4
and mass of accreting body, 12.6, fig. 12.6.1
time of initiation, 12.6, fig. 12.6.1
types
early
defined, 12.9
for planets, 12.9, fig. 12.9.1
and spin inclination of embryo, 13.6, fig. 13.6.1
and temperature profile of embryo, 12.10-12.11
delayed
defined, 12.9
for planets, 12.9, fig. 12.9.1
and spin inclination of embryo, 13.6, fig. 13.6.1
and temperature profile of embryo, 12.10-12.11
late
defined, 12.9
for planets, 12.9, fig. 12.9.1
spin inclination of embryo, 13.6, fig. 13.6.1

temperature profile of embryo, 12.10-12.11
accretion, statistical (see accretion, gravitational)
accretional catastrophe (see accretion, runaway)
accretional processes
and chemical differentiation of accreted body
formation of crust, core, mantle, 12.13, 20.5
hot spot front
general characteristics, 12.12-12.13
supportive evidence on Moon and Earth, 24.7
and embryo spin, 13.1-13.6
and heating effects (see also heating effects)
planetesimal impact melting, 12.12-12.13, 20.3
temperature profiles of accreted bodies, 12.10-12.11
in jet streams
brief summary, 22.5
general characteristics, 11.1, 12.6
by density waves, 14.3, 14.8, 19.3
in meteor streams, 14.3
versus fragmentation processes (see also collisions)
in asteroid belt, 7.1, 7.3
summary of collision effects, 12.3, 22.8
transition between fragmentation and accretion, 7.4, 12.3
accumulation (see accretion)
actinides and gravitative differentiation, 12.13
actualistic principle
defined, 1.1
applications of
hetegonic plasma, 15.4
interpretation of meteorite phenomena, 22.1
models of accretion, 11.7
partial corotation, 18.1
present structure of the solar system, 15.1
in studying solar system evolution, 1.1, 11.1
age (crystallization, degassing, gas retention and exposure) in meteorites, 22.9
aggregates (see grains, accretion of)
aggregation (see accretion, nongravitational)
alpha-Capricornid meteor stream association with comet, 14.4
Amalthea (see Jovian satellite system)
Amor asteroids (see Apollo-Amor asteroids)
angular momentum, orbital
defined, 2.1

of accreting grains and embryo spin, 13.1
distribution in solar system and Laplacian model, 2.4-2.5, 16.2
and gravitational collapse, 11.2, 16.2
and orbital stability, 10.1
for planets and satellites, table 2.1.1, figs. 2.3.1-2.3.4
transfer from primary by hydromagnetic effects during formation of secondary bodies
introduction, 16.1-16.2
model derivation, 16.3, fig. 16.3.1
modifications of model, 16.3-16.5
outer limit of solar angular momentum transfer, 19.1-19.2
Apollo-Amor asteroids
definition, 4.6
orbital parameters, 4.6, fig. 4.4.1
genetic relationships
with comets, 4.6
with meteorites, 22.2
hetegonic model, 19.8, fig. 19.8.2, table 19.8.1
traditional view, 19.8, fig. 19.8.1
apparent attraction, 6.4-6.5
approach, "first" and "second" (see plasma, pseudo, and plasma, real)
Ariel (see Uranian satellite system)
asteroidal families
defined, 4.3
general characteristics, 14.7
asteroidal jet streams (see jet streams, types)
asteroids (see also Apollo-Amor, Hilda, Hungaria, main belt, subvisual and Trojan asteroids; Ceres; Thule; Toro; Vesta)
formation and genetic relationships
accretion of asteroids in jet streams
summary, 14.7
asteroidal families, 4.3, 14.7
asteroidal jet streams, 4.3, 14.7
hetegonic model, 19.8, fig. 19.8.2, table 19.8.1
origin from exploded planet, 4.3, 11.8, 19.8
meteorite origin from asteroids, 22.2
motivation for asteroidal studies, 4.3, 18.7
orbital motion
forces governing, 5.1-5.2, fig. 5.1.1
orbital parameters, 4.1, 4.3-4.5, table 4.3.1, figs. 4.3.1-4.3.3, table 9.7.1
resonances, 8.5, table 8.5.1
physical properties
composition, 20.5, table 20.5.1, fig. 20.7.1

mass, 4.3, table 4.3.1
mass distribution, 4.1, 4.3, fig. 4.3.4
and resonance gaps, 4.3, fig. 4.3.4
(M,a) diagram, fig. 4.3.4
radius, equatorial, table 4.3.1
size spectra, 4.3
surface layer composition, 20.5
compared to that of known meteorites, 22.2
visual magnitude, tables 4.3.1, 9.7.1
atmosphere, terrestrial
formation theories
summary, 26.7
accretion phenomena, 26.1, 26.3-26.4
post-accretional degassing of the Earth, 26.2-26.3, 26.5
planetesimals as source of atmosphere, 26.2
atomic abundances of cosmically important elements, table 21.5.1
aurorae as examples of cosmic plasmas, 15.3
B cloud (see clouds (A, B, C, D))
band structure of spacing between secondary bodies
general discussion, 21.1
basic model, 21.11, figs. 21.11.1-21.11.2
apparent exceptions to model, 21.2, 23.9
bands of secondary bodies (see also band structure; gravitational potential energy)
defined, 21.2, fig. 21.2.1
general description, 21.2
and bands of elements, 21.5, fig. 21.5.1, table 21.5.1
chemical composition of bands
basic model, 21.11-21.12, figs. 21.11.1-21.11.2
comparison with bands of elements, 21.5, fig. 21.5.1, table 21.5.1
effects of transplanetary condensation, 21.12, fig. 21.12.3
comparative study of groups within each band, 21.3
formation of bands, 21.11-21.12
slope of bands, 23.9
C cloud (see clouds (A, B, C, D))
Callisto (see Jovian satellite system)
capture, resonance (see resonance)
capture theory for satellites
Moon
brief summary, 24.9
general description, 24.4
destruction of Earth's satellites, 24.6

tidal evolution of lunar orbit, 24.5, fig. 24.5.1
retrograde satellites, 24.4
Cassini's division (see Saturnian rings, structure)
catastrophic accretion (see accretion, runaway)
celestial mechanics
guiding center approximation, 3.1-3.7
treating orbital motion, 5.1-5.2
central body (see primary body)
Ceres (see also asteroids)
physical properties
mass, radius, density, table 20.5.1
spin period, table 9.7.1
surface features, 20.5
visual magnitude, table 9.7.1
semi-major axis, fig. 20.7.1, table 20.5.1
chemical differentiation (see differentiation, chemical)
chemical separation (see differentiation, chemical)
chondrites (see meteorites)
chondrules (see meteorites)
chromosphere as an example of a cosmic plasma, 15.3
circumstellar dust envelopes
and information on early solar system environment, 15.4
circumstellar regions, ionization in, 15.1
cloud, source (see source cloud)
clouds (A, B, C, D)
defined, 21.11
introduction, 2.5, 18.10, 21.11
associated gravitational potential energy bands, 21.11, figs. 21.11-21.11.2
bodies formed in each cloud, 21.11, 23.8
composition of clouds
basic model, 21.11-21.12
compared to bodies formed in each cloud, 21.11
mass distribution, 23.6-23.8
controlling element, 21.11, figs. 21.11.1-21.11.2
dominant critical velocity, 21.11, fig. 21.11.2
overlapping of clouds
general discussion, 24.1
affecting composition of Moon and Earth, 24.8
collapse, gravitational (see gravitational collapse)
collision velocity
of asteroids, 11.5

effects on fragmentation and accretion, 7.4, 11.5, fig. 22.8.1
in jet streams, 11.5
subsonic, 12.3
supersonic, 12.3, 22.6
collisions (see also fragmentation; accretion; negative diffusion)

and accretional processes
accretion versus fragmentation, 7.4, 12.3, 22.8, fig. 22.8.1
nongravitational accretion, 7.4, 11.5, 22.7
of polarized particles, 7.4, figs. 7.4.1-7.4.2, 11.5, 12.3
of magnetized particles, 12.3, 22.7, fig. 22.7.1
grains condensing from a partially corotating plasma, 18.2.1
heating effects, 12.12-12.13

effects on orbital motion
in general, 5.2, fig. 5.1.1, 6.3, 6.6-6.9, 18.2
and Kirkwood gaps, 8.6
negative diffusion, 6.6, fig. 6.6.1
evidence from meteorites, 22.6
perturbing Kepler motion, 5.2
in jet streams
contraction of jet streams, 6.8
energy loss due to collisions, 12.5
evidence from meteorites, 22.6
coma, cometary, 4.1
cometary asteroids (see Apollo-Amor asteroids)
comets
composition
inferred from emissions, 14.6
mass, 4.1
nuclei, 14.3-14.4, 14.6
formation and genetic relationships
hetegonic model, 19.8, fig. 19.8.2, table 19.8.1
in meteor streams, 14.2-14.5, 19.6, 19.8
as source of
Apollo-Amor asteroids, 4.6
meteorites, 22.2
traditional view, 11.8, 19.8, fig. 19.8.1
orbital motion
governing forces and effects, 5.1-5.2, fig. 5.1.1
diffusion in aphelion due to planetary encounters, 19.5

orbital parameters, 4.6, fig. 4.6.1
comets, long-period, 4.6
formation and genetic relationships
accretion in meteor/jet streams in transplanetary space, 19.3-19.4,19.6, fig. 19.8.2
alternative views of origin, 19.4
origin in interstellar space, 4.6
primeval matter in solar system, 19.5
and short-period comets, 14.5
comets, short-period
definition, 4.1, 4.6
formation and genetic relationships
and long-period comets, 4.6, 14.5
close approach to Jupiter, 14.5
in meteor streams, 14.5, 19.8
comet cloud, Oort's, 14.5, 19.4
cometary reservoir, 4.6, 14.5, 19.4
commensurability (see resonance) commensurability , near -
general characteristics, 8.9
as broken resonance, 8.9
examples, 8.9
relation to retrograde satellites, 8.9
and stability of orbital motion, 10.2
comparative studies of planets/satellites
asteroid belt and Saturnian rings, 18.8
composition of celestial bodies, 20.7
composition of Earth and Moon, 24.8
to deduce origin of Moon, 24.2-24.4
groups of secondary bodies
    mass distribution, 23.7
    within each band of gravitational potential energy, 21.3
satellite systems, 24.2
to understand early properties of the Sun, 25.1-25.5
composition of celestial bodies (see also planets and satellite systems by name)
direct determinations
difficulty of interpretation, 20.3-20.4
sources of information, 20.2
theoretically deduced
limitation upon deduction due to unknown
solar composition, 20.6
states of matter, 20.4
Laplacian model, 20.1, 20.6-20.7
as function of
mass, 20.5, figs. 20.5.1 20.5.2

primary's radiation, 20.7, 25.5
radial distance from primary, 20.7
from hetegonic processes of
accretion, 12.12-12.13
emplacement of matter, 21.11-21.12
condensation (see also condensation, transplanetary)
condensation products
and formation of celestial bodies, 19.8, fig. 19.8.2, table 19.
interpretation of meteorite data, 22.1
occlusion of noble gases during crystal growth, 26.2
orbital parameters of resulting matter, 17.5, fig. 17.5.1
in cosmic plasmas
in filaments or superprominences, 16.7
from partially corotating plasma, 17.5, fig. 17.5.1
processes in plasma environment, 15.3, 26.2
factors affecting
thermal radiation of early Sun, 2.5, 20.7, 25.5
transfer of angular momentum from primary to seconder 16.5, fig. 16.6.1
of grains
from plasma
in circumstellar regions, 15.1
cosmic plasma, 15.3
partially corotating plasma, 17.5, fig. 17.5.1, 18.2, fig.18.2.1
temperature considerations, 15.3, 22.1
condensation, transplanetary
defined, 19.1
condensation products, 19.3
ablation in plasma clouds, 21.12
formation of celestial bodies, 19.8, fig. 19.8.2, table 19.8.1
formation of jet streams, 19.3
controlling element (see element, dominant/controlling)
core (see Earth, composition; Venus, composition)
cosmic atomic abundances
listed, table 21.5.1
and composition of celestial bodies, 20.1
cosmic plasma physics (see plasma physics)
cosmic rays and irradiation of meteorites, 22.9
coupling, resonance (see resonance)
crepe ring (see Saturnian rings)
critical velocity
defined, 21.8

general characteristics, 21.8, eq. 21.10.1
dominant/controlling critical velocity
basic discussion, 21.11, figs. 21.11.1-21.11.2
and composition of clouds (A, B, C, D), 21.12, figs. 21.12.1-21.12.2
experiments, 21.7-21.8
theoretical studies
review cited, 21.9
analogy to Franck-Hertz law, 21.9
values of critical velocity for
elements, table 21.5.1
polynuclear molecules, 21.11
critical velocity phenomenon
brief discussion, 21.7
discussion of ionization velocity, 21.4-21.5
for different gases (H, He, Ne, O, D, Ar), 21.8
in partially corotating plasma, 21.13
critical velocity sphere defined, 23.2
cross-section spectra, 7.2
crust (see Earth, composition; Moon, composition; differentiation; heating effects)
currents in hetegonic plasmas (see plasma, hetegonic)
D cloud (see clouds (A, B, C, D))
dark clouds
properties of, 1.4, 15.4
formation of bodies in, 15.4, 25.7
degassing of Earth's interior as suggested source of atmosphere, 26.2-26.3, 26.5
Deimos (see Martian satellite system)
density, average
of asteroids (Ceres, Vesta), table 20.5.1
of planets, table 2.1.1, table 20.5.1
of satellites, table 20.5.1
density, distributed
defined, 2.4
of the planets, 2.5, table 2.1.1, fig. 2.5.1
of the satellites, 2.5, table 2.1.2
Jovian, fig. 2.5.2
Saturnian, fig. 2.5.4
Uranian, fig. 2.5.3
density waves in jet streams, 14.3, 14.8, 19.3
deuterium-burning Sun, 25.6
deuterium, critical velocity of, 21.8
diamond in meteorites, 11.8

dielectric particles in space, 7.4
dielectric polarization (see electrostatic polarization)
differentiation, chemical
and composition of celestial bodies, 20.3
during accretion (see also hot spot front)
heating effects, 12.12- 12.13
gravitational effects, 12.12 12.13
of volatiles, 21.12, 26.4
during condensation, 21.12
during emplacement of matter, 21.11
of Earth, 12.12-12.13, 20.5, 26.7
lacking in small bodies, 20.3
of Moon, 12.12-12.13, 24.7
Dione (see Saturnian satellite system)
disc of uniform density (see Laplacian-type models)
disruption (see fragmentation)
distributed density (see density, distributed)
dominant critical velocity (see critical velocity, dominant)
double planet systems, general discussion, 24.1
double-layer, electrostatic (see electrostatic double-layer)
dust, interplanetary (see condensation, transplanetary; interplanetary dust)
dusty plasma (see plasma, dusty)
Earth (see also planets)
atmosphere (see atmosphere, terrestrial)
ocean (see ocean)
formation and accretion effects (see also accretion)
brief summary, 26.3
of core, crust and mantle, 12.10-12.13, fig. 12.11.1, 20.5, 26.3, 26.5
orbital parameters, table 2.1.1
physical properties, table 2.1.1
composition, 20.5, table 20.5.1, figs. 20.5.1, 20.7.1
core, 20.5
crust, 26.3, 26.5
mantle, 20.5, 26.3, 26.5
and overlap of A and B clouds, 24.8
spin
as acquired during accretion, 13.1-13.6
changes due to lunar tidal braking, 9.4
inclination of spin axis, 13.6
prior to capture of Moon, methods of estimation 24.3
temperature profile
and accretion processes, 12.10-12.11, fig. 12.11.1, 20.5

evidence against complete melting, 26.3
and formation of ocean and atmosphere, 26.3, fig. 26.3.1
satellites (see also Moon)
absence of regular system, 21.2, 23.9
prior to Moon capture
brief summary, 24.9
and lunar mare and basins, 24.6, fig. 24.
destruction of regular satellites, 24.6
mass of satellites, 24.3, fig. 24.3.1
number of satellites, 24.3, fig. 24.3.2
tides
amplitude, table 9.2.1, fig. 9.4.1
tidal braking by the Moon, 9.4
eccentricity
definition, 2.1
guiding center treatment, 3.3
for orbits of
asteroids, 4.3-4.4, figs. 4.3.1, 4.4.1, table 4.3.1
comets, fig. 4.6.1
meteor streams, fig. 4.6.1
planets, table 2.1.1
satellites, table 2.1.2 2.1.3
of 1/3 for orbits of grains condensed from partially corotating plasma, 17.5, fig. 17.5.1
ejecta (see collisions; fragmentation)
electret particles in space, 7.4, figs. 7.4.1-7.4.2
electric breakdown analogy to critical velocity phenomena, 21.4
electric polarization of
interplanetary dust, 7.4, figs. 7.4.1-7.4.2
grains and accretion processes, 11.5, 12.3
electromagnetic effects (see also hydromagnetic effects, magnetic effects)
in interplanetary plasma, 1.4, 5.3, fig. 5.1.1, 15.1
ionization and arrest of infalling gas, 21.4
electron energy increase associated with critical velocity phenomenon, 21.8
electrostatic double layers in plasmas
general properties, 15.3, fig. 15.3.1
experimental review cited, 15.3
in magnetosphere, 16.3
electrostatic polarization of grains in space, 7.4, figs. 7.4.1-7.4.2, 11.5, 12..
element, dominant/controlling
for clouds (A, B, C, D), 21.11-21.12
and critical velocity phenomenon, 21.11

ellipticity (see oblateness)
embryo (see also planetesimal)
accretion
in jet streams, 12.3-12.6
brief summary, 12.6, fig. 12.6.1
heating effects, 12.12-12.13
spin produced by accretion, 13.1-13.6
as function of size and mass, 13.3
inclination of spin axis, 13.6
prograde, 13.4
retrograde, 13.4
temperature profile, 12.10
emplacement of matter (see also critical velocity)
composition of accreted bodies, 20.5
energy release during emplacement, 23.1
ionization of infalling gas, 21.2-21.5, 21.11, figs. 21.11.1-21.11.2, 23.1-23.4
positioning of gravitational potential energy bands, 21.11, figs. 21.11.1-21.11.2
spacing among groups of secondary bodies, 21.2-21.5, 21.11, figs. 21.2.1-21.2.2
and spin of primary body, 23.1-23.10
Enceladus (see Saturnian satellite system)
energy release
during emplacement of matter, 23.1
during transfer of angular momentum from primary to secondary body17.6
envelopes, circumstellar dust (see circumstellar dust envelopes)
epicycle (see guiding center method; orbital motion)
escape velocity
defined, 2.2
for planets, table 2.1.1
Europa (see Jovian satellite system)
evolutionary stages in development of a primary/secondary system
pertient studies of
small bodies, 4.1-4.3, 18.7, 22.1, 22.10
spin of celestial bodies, 9.1, 9.8
brief synopsis, 1.3, 16.6, fig. 16.6.1, fig. 16.7.1, 27.1
formation of the Sun, 1.4, 25.7
emplacement, ionization and plasma capture of matter (see also emplacement;
ionization of infalling gas; critical velocity phenomeno:
brief description, 1.3
basic characteristics, 1.4
ionization of infalling gas, 21.2-21.5, 21.11, figs. 21.11.1-21.11, 23.1-23.4
resulting mass distribution as a function of primary spin, 23.5-23.
hydromagnetic transfer of angular momentum (see also angular momentum, transfer;

condensation; partial corotation)
transfer of angular momentum from primary to secondary, 16.1-16.6
partial corotation
defined, 17.1
general characteristics, 17.2
observational verification, 18.6, 18.8-18.9
condensation
summary, 19.8, fig. 19.8.2, table 19.8.1
from partially corotating plasma, 17.5, fig. 17.5.1
and primary's radiation, 2.4, 20.7, 25.5
temperature considerations, 1.4, 15.3, 22.1
accretional (see also accretion)
defined, 1.3
general characteristics, 1.4, 11.1
summary, 19.8, fig. 19.8.2, table 19.8.1
general prerequisites, 11.7
in jet streams; brief summary, 21.4, fig. 21.4.1, 22.5
possible present-day examples, 11.6
types of accretion
planetesimal, 11.3
gravitational, 11.4 (see also accretion, gravitational)
nongravitational, 11.5 (see also accretion,nongravitational)
post-accretional (see also stability of orbits)
defined, 1.3
general characteristics, 1.4
in asteroid belt, 4.2, 10.3
resonance structures, 10.2
Saturnian rings, 10.3
spin isochronism, 10.4
stability of orbital motion, 10.1
exact resonance (see resonance)
exploded planet hypothesis for origin of small bodies
asteroids, 4.3, 11.8, 19.8, fig. 19.8.1
comets, 11.8
meteorites and meteoroids, 11.8, 22.1, 26.2
arguments against explosion hypothesis, 11.8
exposure dosage in meteorites, 22.9
fall-down ratio (see two-thirds law)
families, asteroidal
general characteristics, 14.7
relation to jet streams, 4.3

similarity of orbital parameters, 4.
Ferraro isorotation
basic assumptions, 16.3
general characteristics, 16.3
resulting plasma distribution, 17.2
filaments in plasmas (see hydromagnetic effects; plasma, real; super-prominences)
first approach (see plasma, pseudo)
Flora family of asteroids, 4.3
fluffy aggregates (see also grains, accretion)
formation of, 7.4, figs. 7.4.1-7.4.2, 11.5, 12.3, 22.7, fig. 22.7.1
accretion of, 7.4, 11.5, 12.3
fluffy state of matter
knowledge of
basic lack, 20.4
experimental studies, 7.4
in meteorites, 20.4, 22.7, fig. 22.7.1
examples
surface of Martian satellites, 20.4, fig. 20.4.1
in meteorites, figs. 7.4.1-7.4.2, fig. 22.3.1
focusing (see apparent attraction; Kepler motion, collision preturbed; jet streams)
formation of planets and satellites (see accretion)
formation of stars
by gravitational collapse, 11.2
by stellesimal accretion, 25.7
formative era (see hetegonic era)
fractionation (see differentiation, chemical)
fragmentation
simple model and size spectra, 7.3
transition between fragmentation and accretion, 7.4, 12.3
versus accretion
in asteroid belt, 7.1, 7.3
evidence in meteorites, 22.4-22.8, fig. 22.8.1
summary of collision effects, 22.8, fig. 22.8.1
front, hot spot (see hot spot front)
frozen-in field lines
description, 15.3, table 15.3.1
and Ferraro isorotation, 16.3, fig. 16.3.1
gale, solar (see solar gale)
Ganymede (see Jovian satellite system)
gaps (see Kirkwood gaps; resonance effects)

gas, accretion, 11.4 (see also volatiles)
gas, infall
duration of infall, 12.8, 12.10
general discussion, 21.1
ionization of, 21.2-21.5, 21.11, figs. 21.11.1-21.11.2, 23.1-23.4
interaction with plasma (see critical velocity phenomenon)
gas content of jet streams (see jet streams, composition)
genealogy of celestial bodies
hetegonic model, 19.8, fig. 19.8.2, table 19.8.1
traditional view, 19.8, fig. 19.8.1
Giacobinid meteors
composition compared to that of chondritic meteorites, 22.2
Giacobini-Zinner comet, 22.2
Giuli's gravitational accretion theory, 13.4-13.5
grain ablation of transplanetary condensates passing through plasma clouds, 21.12
grains
accretion (see also accretion)
required orbital and physical properties of the grains, 15.1, 15.5, 11.7
gravitational accretion
imparting spin to embryo, 13.1-13.6
in jet streams, 12.3-12.6
nongravitational accretion
electrically polarized grains, 7.4, figs. 7.4.1-7.4.2, 11.5, 12.3
magnetized grains, 12.3, 22.7, fig. 22.7.1
selective accretion of metal grains, 20.5
composition, 26.2
condensation (see also condensation of grains)
condensation products
crystal growth, 26.2, fig. 7.1.1
interpretation from meteorite data, 22.1
condensation environment

    in cosmic plasmas, 15.1, 15.3, 26.2
    in filaments or superprominences, 16.7
    in partially corotating plasmas, 16.5,fig. 16.6.1, 17.5,fig. 17.5.1
    radiation, 5.5, 11.5

temperature considerations, 15.3, 22.1
thermal radiation of primary, 2.4, 20.7, 25.5
orbital motion governed by
accretional processes, 11.7

collisions, 5.2, 6.3, 6.9, fig. 6.9.1, 18.2
gravitational and electromagnetic forces, 5.4
partially corotating plasma, 17.1, 17.5, 18.2
grains, asteroidal (see subvisual asteroids)
gravitational accretion (see accretion, gravitational)
gravitational collapse (see also Laplacian-type models)
formation of stars, planets and satellites, 11.2
objections against, 11.2, fig. 11.2.1, table 11.2.1, 21.1
gravitational effects
formation of jet streams, 6.4-6.5
on orbital motion
of large bodies, 5.2, fig. 5.1.1
of small bodies, fig. 5.1.1, 5.4
of secondary versus primary body, 11.2, fig. 11.2.1, table 11.2.1
gravitational potential energy
defined, 21.2
of bands of secondary bodies, 21.2, fig. 21.2.1
of cosmically important elements, 21.5, table 21.5.1, fig. 21.5.1
density of celestial bodies, 20.7, figs. 20.7.1, 21.12.3
equated to ionization energy to study band formation, 21.5, fig. 21.5.1, table 21.5.1
ionization of infalling gas, 21.4
gravitational potential energy bands (see bands of secondary bodies)
gravitative differentiation (see differentiation; heating effects)
grazing planet (satellite)
defined, 2.3
orbital parameters, table 2.1.1 (table 2.1.2)
groups of secondary bodies (see also bands of secondary bodies)
introduction, 2.5
listed, table 2.5.1, 18.10
and clouds (A, B, C, D), 23.8
comparative study, 21.3
formation of groups, 18.10, fig. 18.10.1, 23.1-23.4
absence of expected groups explained, 21.2, 23.8
and gravitational potential energy bands
description of bands, 21.2, fig. 21.2.1
relation to primary mass, 21.2, fig. 21.2.1
properties
mass distribution within each group, 23.6-23.7, fig. 2:
number of bodies in each group
as a function of T_{ion}/τ figs. 23.5.1, 23.6.1, 24.3, fig. 24.3.2
spacing between groups

basic model, 21.11, figs. 21.11.1-21.11.2
between Mars and Jupiter, 18.10
and emplacement of matter, 21.2-21.5, fig. 21.2, fig. 21.11.2
spacing within a group, 18.10
guiding center method (see also orbital motion)
definition, 3.1
motivation, 3.1
and apparent attraction, 6.4-6.5
and eccentricity, inclination, pericenter and nodes, 3.3
in unperturbed $1/r^2$ gravitational field, 3.4
of orbit with large eccentricity, 3.5
hardness spectrum of radiation
in Fayetteville meteorite, fig. 22.9.1
heat, solar
prevention of condensation, 2.5, 20.7, 25.5
heat front (see hot spot front)
heating, frictional (see grain ablation; pericentric frictional heating)
heating, pulsed (see pericentric frictional heating)
heating effects (see also differentiation; hot spot front)
during accretion
of growing embryo, 12.10
of planets, 12.11 12.13, fig. 12.11.1
due to impact of accreting grains and planetesimals, 12.12-12.13, 20.3
temperature profiles of accreted bodies, 12.10 12.11
evidence
in meteorites, 11.8, 22.4, 22.6
in lunar and terrestrial crusts, 24.7
frictional heating at pericenter of orbit, 11.8, 21.12, 22.4
melting of planetary interior by radiogenic heat, 20.5
primary's radiation and composition of secondary, 20.7, 25.5
helium, critical velocity of, 21.8
hetegonic, defined, 1.2
hetegonic effects, evidence of in
asteroid belt, 10.3, 18.8, fig. 18.8.1
meteorites, 16.1, 22.1, 22.6, 22.9-22.10
resonances, 8.5, 10.2
Saturnian rings, 8.7, 10.3, 18.6, figs. 18.6.3-18.6.4
hetegonic era (see also models of solar system evolution, hetegonic)
differentiation processes during, 20.3
magnetic fields during, 16.1, 16.3, table 16.3.1, 19.2, 25.2-25.3
solar radiation during, 5.5, 16.8, 22.9, 25.5

hetegonic jet streams (see jet streams, types)
hetegonic nebulae (see nebulae, hetegonic)
hetegonic principle
introduced, 1.2
general characteristics, 16.9, fig. 16.9.1
limitation of, 16.9
applications to
composition of celestial bodies, 20.7
formation of clouds (A, B, C, D), 21.11
formation of planetary and satellite systems, 21.11
interpretation of meteorite data, 22.1
origin of Moon, 24.1-24.4
resonance theory, 9.6
study of early Sun, 25.1
mass, 25.2
magnetic field, 25.3
radiation, 25.5
spin period, 25.4
hetegonic processes (see evolutionary stages)
hetegonic shadow
defined, 18.6
examples
Jupiter, 18.8, fig. 18.8.1
main belt asteroids, 18.8, fig. 18.8.1
Mimas, 18.6, figs. 18.6.3-18.6.4
Saturnian rings, 18.6, figs. 18.6.3-18.6.4
hetegony
defined, 1.2
high pressure experiments
and composition of core material in celestial bodies, 20.4
Hilda asteroids
orbital motion
orbital parameters, 4.4, fig. 4.3.3
and Kirkwood gaps, 8.6
resonance with Jupiter, 4.4, 8.5, fig. 8.5.4, table 8.5.1
possible present-day accretion, 11.6
Hirayama families
definition, 4.3
and "proper elements" of asteroid orbits, 4.3, fig. 4.3.5, table 4.3.2
homogeneous disc as precursor medium for planetary system (see Laplacian-type models)

Homopolar device for critical velocity experiments, 21.8
Honda-Mrkos-PaJduskova comet, 14.4
hot spot front
defined, 12.12
brief summary, 26.4
general characteristics and effects, 12.12-12.13
differentiation of accreting body, 12.13, 20.5
release of water from impacting planetesimals, 26.4
supportive evidence
volatile loss from Earth and Moon, 24.7
Hungaria asteroids
orbital motion, 4.4, fig. 4.4.1, fig. 4.3.3
possible resonance with Jupiter, 4.4
hydrated minerals in meteorites, 11.8
hydrogen, critical velocity of, 21.8
hydromagnetic effects
brief summary, 15.5
in cosmic plasmas, 1.4, 15.3, 15.1
during transfer of angular momentum from primary to secondary body
heating and ionizing of plasma, 17.6
magnitude of effects, 16.2-16.6
model of transfer, 16.3
ionization and arrest of infalling gas, 21.2 21.5, 21.11, figs. 21.11.1-21.11.2, 23.1 23.4
hydromagnetic parameter, characteristic
defined, 15.1
values, table 15.1.1
hydroxyl
    emission from comets, 14.6
    source of ocean and atmosphere in planetesimal hydroxysilicates, 26.2
hydroxysilicates in planetesimals and meteorites
postulated origin in exploded planet, 26.2
grown in laboratory, 26.2
Hyperion (see Saturnian satellite system)
Iapetus (see Saturnian satellite system)
icy conglomerate
as comet nucleus, 14.3
impact (see collisions) impact melting
differentiation of embryo matter, 12.12-12.13
due to accreting planetesimals, 12.12-12.13, 20.3
hot spot front, 12.12 12.13, 20.5, 26.4
impurities in clouds (A, B, C, D) 21.11-21.12

inclination, orbital
asteroids 4.3-4.4, figs. 4.3.2, 4.4.1, table 4.3.1
comets, fig. 4.6.1
guiding center approximation, 3.3
meteor streams, fig. 4.6.1
planets, table 2.1.1
satellites, tables 2.1.2-2.1.3
inclination of equator to orbital plane
and accretion processes, 13.6
of the planets, table 2.1.1, fig. 13.6.1
inelasticity of collisions (see negative diffusion)
evidence from meteorites, 22.6
and negative diffusion theory, 6.6
inertia, normalized moment of
defined, 2.2
for planets, table 2.1.1
infall of matter
defined, 21.1
general characteristics, 21.1
basic model, 21.11-21.12, figs. 21.12.1-21.12.2
interaction with local plasma
introduction, 21.4
arrest of infall due to
ionization, 23.1-23.10
trapping in clouds (A, B, C, D) 21.12, fig. 21.12.2
energy release, 23.1
resulting mass distribution, 23.1-23.10
resulting spacing of bodies, 21.2-21.5, figs. 21.2.1, 21.11.2, 23.6, fig. 23.6.1
infall velocity and arrest of infalling gas, 21.4 (see also critical velocity phenomenon)
infall time (see time (duration) of infall of matter)
instabilities in plasma, 15.3
instability, gravitational (see gravitational collapse)
interaction, mutual effects of particles and orbital motion, 6.4
internal electric polarization (see electrostatic polarization)
internal velocity (see velocity, internal)
interplanetary condensation (see condensation)
interplanetary dust (see also grains; condensation, transplanetary)
accretion to form celestial bodies, 19.8, fig. 19.8.2, table 19.8.1
forces governing orbital motion, 5.1-5.6, fig. 5.1.1
interplanetary medium
defined, 6.2
effects on orbital motion, 6.2
interplanetary space

defined, 19.2
interstellar dust
in transplanetary space, 19.3
interstellar molecules, critical velocity of, 21.11
Io (see Jovian satellite system)
iodine
I^{129}/Xe^{129} ratios in meteorites, 22.9
ionization
in circumstellar regions, 15.1
degree of
in cosmic plasmas, 15.3
in hetegonic plasmas, 15.1, 23.1-23.4
ionization distance (see also critical velocity phenomenon)
introduced, 21.4
and mass distribution within groups of secondary bodies, 23.1-23.8
modified for partially corotating plasma, 21.13
ionization energy of infalling gas, 21.5, fig. 21.5.1, table 21.5.1
ionization of infalling gas
by interaction with plasma, 15.3, 21.4
complete ionization
theory 23.2, fig. 23.2.1
giant planets, 23.2, fig. 23.2.2, table 23.2.1
outer Saturnian satellites, 23.2
partial ionization, 23.3, fig. 23.3.1
ionization potential
of cosmically important elements as a function of gravitational potential energy, 21.5, fig. 21.5.1, table 21.5.1
ionization velocity of infalling gas, 21.4 (see also critical velocity phenomenon)
iron
in cores of Earth, Mercury, Pluto and Venus, 20.5
irradiation effects
during hetegonic era, 5.5, 16.8, 22.9, 25.5
irradiation record in meteorites, 16.8, 22.9, fig. 22.9.1
irregular groups, defined, table 2.5.1
isochronism of spins
defined, 9.7, fig. 9.7.1, table 9.7.1
and accretional processes, 13.3
and accretional theory, 13.4
and stability of the solar system, 10.4
Janus (see Saturnian satellite system)
jet streams

defined, 1.4
general characteristics, 4.3, 6.9, 11.5, 12.6
and accretional processes
brief summary, 21.4, fig. 21.4.1, 22.5
density waves, 14.3, 14.8, 19.3
nongravitational accretion, 7.4, 11.5, 12.3, 22.7
resolution of objections.to accretional formation of bodies, 11.1, 12.2
simple model, 12.2-12.6
limitations of model, 12.7
spin acquisition by accreting body, 13.1-13.6
physical properties simple toroid model, 12.2
composition
 deduced from meteorite composition, 22.6
 of distinct streams, 22.9
 gas content, 22.6
density
defined, 12.3
and embryo growth, 12.6, fig. 12.6.1
numerical values, 12.8, table 12.8.1
for planetary jet streams, table 12.8.1
volume
simple model, 12.2
for planetary jet streams, table 12.8.1
evolution of jet streams
summary, 6.9
energy balance, 12.5
mass
assimilation of mass, 6.9, fig. 6.9.1, 12.4
compared to Laplacian rings and Saturnian rings, 6.8
orbital characteristics
contraction of jet stream, 6.8-6.9, 12.5-12.6, fig. 12.6.1
dispersion of jet stream, 6.8-6.9
Kepler motion, 6.1-6.10
negative diffusion, 6.6, fig. 6.6.1, 6.8-6.9
profile of a jet stream, 4.3, 12.7, 11.5
types
list, 6.10
asteroidal
defined, 4.3
general characteristics, 14.7
evolutionary processes in, 14.7
focusing of, 4.3

Flora A jet stream, 4.3, fig. 4.3.6
cometary, 14.7
hetegonic
compared to asteroidal, 12.7, 12.2
and formation of planets and satellites, 12
meteor streams, 14.2
transplanetary, 19.3
Jovian satellite system (see also satellite systems)
comparative study with other satellite systems, 21.3
orbital motion
orbital parameters, table 2.1.2
angular momentum, fig. 2.3.2
resonances
Io-Ganymede-Europa, 8.5
retrograde satellites
capture theory, 24.4
relationship with Trojan asteroids, 8.5
physical properties
physical properties, tables 2.1.2-2.1.3
composition and primary's radiation, 20.7
density, average, table 20.5.1, fig. 20.7.1
density, distributed, table 2.1.2, fig. 2.5.2
mass distribution, 2.4-2.5, fig. 2.5.2, 23.6-23.7
tidal deformation table 9.2.1
Jupiter (see also planets)
orbital motion
orbital parameters, table 2.1.1
resonances
Hilda asteroids, 8.5-8.6, fig. 8.5.4, table 8.5.1
Thule, 8.5, table 8.5.1, 8.6
Trojan asteroids, 8.5, fig. 8.5.3, table 8.5.1
physical properties, table 2.1.1
composition, 20.5, table 20.5.1, fig. 20.5.2, fig. 20.7.1
excess energy emission, 20.5
inclination of spin axis, 13.6
temperature profile, 12.10-12.11, fig. 12.11.1
tidal braking of spin by satellites, 9.4
tidal deformations, table 9.2.1
satellites (see Jovian satellite system)
Jupiter 6-12 (see Jovian satellite system)
Jupiter capture of long-period bodies to form short-period bodies
comets, 14.5, 19.5-19.7, fig. 19.8.1
meteoroids, 19.5, 19.7, fig. 19.8.2

Kepler motion
of asteroids, 5.2, fig. 5.1.1
guiding center approximation, 3.1-3.7, fig. 3.3.1
of interacting bodies 6.1-6.10
and jet streams, 6.1-6.10
transition from partial corotation, 17.5
Kepler motion, collision perturbed
describing mutual interaction of bodies in Kepler orbits, 5.1-5.2, 5.1.1, 6.3, 6.6-6.9
of grains condensed from partially corotating plasma, 18.2
in Saturnian rings, 18.5
kinematic image of condensing plasma
general explanation, 18.5
in asteroid belt, 18.8
in Saturnian rings, 18.5-18.6
Kirkwood gaps
defined, 4.3
collision effects, 8.6
in contrast to captured asteroids at resonance points of Jupiter, 4.4
and resonance effects, 4.3, fig. 4.3.3, 8.5-8.6, 18.6, fig. 18.6.2
Kordylevsky clouds
of small bodies in Moon's orbit, 4.5
Lagrangian points
bodies captured in
Trojans around Jupiter, 4.5
small bodies around the Moon, 4.5
measure of gravitational dominance, 11.2, fig. 11.2.1, table 11.2.1
Laplacian-type models of solar system evolution
general description, 16.2
inadequacies
chemical composition of solar system, 20.1, 20.6-20.7
conservation of angular momentum, 16.2
gravitational collapse, 11.2, 21.1
mass distribution in solar system, 2.4-2.5, 21.1
support of cloud against central body's gravitation, 16.4
and Titius-Bode's law, 2.4
Leonid meteor stream, 14.4
libration
deviation from exact resonance, 8.4
as a measure of resonance stability, 8.4
libration angle
defined, 8.4
libration point (see Lagrangian points)

(M,a) diagram
distribution of asteroid mass, 4.3, fig. 4.3.4
and hetegonic effects, 18.8 fig. 18.8.1
magnesium silicates (see silicates)
magnetic dipole moment
required for transfer of angular momentum from primary to second
body
derived, 16.3
tabulated, table 16.3.1
magnetic effects (see also hydromagnetic effects)
ionization and arrest of infalling gas, 21.2-21.5, 21.11, figs. 21.11-21.11.2, 23.1-23.4
magnetic clustering of grains, 12.3, 22.7, fig. 22.7.1
magnetic field
galactic, 19.2
of primary body during formation of secondary bodies and transfer of angular
momentum
assumptions, 16.1
supportive evidence
observational, 16.1
theoretical, 16.1
values, 16.3
solar magnetic field in hetegonic era, 25.2
transplanetary magnetic field, 19.2
magnetic field lines
and motion of plasma, 15.3, fig. 15.3.4
magnetization, remanent (see remanent magnetization)
magnetization of grains, 12.3, 22.7, fig. 22.7.1
magnetization of a plasma
poloidal versus toroidal, 15.3, fig. 15.3.3
magnetograms, solar (see solar magnetograms)
magnetohydrodynamics (see hydromagnetic effects, hydromagnetic parameter)
magnetohydrodynamics, applications to
emplacement of matter around primary, 16.7, 17.1-17.2, 23.1-23.3
evolutionary theories 1.4 (see also evolutionary stages)
space science, 1 S.1, table 15.1.1
transfer of angular momentum from primary to secondary, 16.1-16.6
magnetosphere
electrostatic double layers
mechanism of establishing, 16.3
theoretical/observational review cited, 16.3
electric field parallel to magnetic field, 16.3, fig. 16.3.1
and information on hetegonic plasmas, 15.4

review of experimental work cited, 15.3
magnitude, visual
of asteroids, 4.3, table 4.3.1, table 9.7.1
main belt asteroids
orbital parameters, 4.3, figs. 4.3.1-4.3.3, fig. 4.4.1
resonances, 4.3, 8.5-8.6
structure
compared to Saturnian rings, 18.6, 18.8
hetegonic effects, 18.8
2/3 fall-down ratio, 18.8, fig. 18.8.1
Kirkwood gaps, 4.3, 8.5-8.6, 18.6, fig. 18.6.2
stability of structure, 10.3
mantle (see Earth, composition)
many body problem in celestial mechanics, 5.2
Mars (see also planets)
orbital parameters, table 2.1.1
physical properties, table 2.1.1
mass, radius, density, table 20.5.1
composition, 20.5, figs. 20.5.1, 20.7.1
spin
tidal braking by satellites, 9.4
inclination of spin axis, 13.6
temperature profile, 12.10-12.11, fig. 12.11.1
satellites (see Martian satellite system)
Martian satellite system (see also satellite systems)
orbital parameters, table 2.1.2
physical properties, table 2.1.2
and bands of secondary bodies, 21.2
surface features of Phobos, fig. 20.4.1
mascons on the Moon, 24.6
mass
asteroids, 4.1, table 4.3.1, figs. 4.3.4, 5.1.1
comets, 4.1, fig. 5.1.1
in jet streams, 12.4, 12.6, fig. 12.6.1
planets, table 2.1.1, fig. 5.1.1, table 20.5.1
satellites, table 2.1.2-2.1.3, fig. 5.1.1, table 20.5.1
solar, for hetegonic Sun, 25.2
mass distribution in solar system (see also density, distributed; composition of celestial bodies)
basic model, 21.11, figs. 21.11.1-21.11.2
bands of secondary bodies

introduced, 21.11, fig. 21.2.1
as function of mass of primary, 21.2, fig. 21.2.1
as function of gravitational potential, 21.2, fig. 21.2.1
and degree of ionization of infalling gas
theory, 23.2 23.3, figs. 23.2.1-23.3.1
observations, 23.2, fig. 23.2.2, table 23.2.1, 23.6-23.8
groups of secondary bodies
comparative study, 21.3
mass distribution within groups, 23.1-23.8
possible explanation of mass distribution
Laplacian disc, 21.1
ejection of mass from primary, 21.1
infall of mass to system, 21.1
present-day distribution
planetary system, 2.4 2.5, fig. 2.5.1, 23.6
satellite systems, 2.4 2.5, figs. 2.5.2-2.5.4, 23.6
spacing among celestial bodies
and critical velocity phenomena, 21.2-21.5, 21.11, figs. 21.11.1-21.11.2
mass emplacement (see emplacement of matter)
mass infall (see infall of matter)
mass spectra, 7.2
medium, interplanetary (see interplanetary medium)
melting
and accretional processes, 12.12-12.13
of embryo by impacting matter, 12.12-12.13
and formation of Earth's core, 20.5
in meteorites, 11.8, 20.4, 22.4, 22.6
Mercury (see also planets)
orbital motion

orbital parameters' table 2.1.1
spin-orbit resonance, 8.8

physical properties
tabulated, table 2.1.1, table 20.5.1
composition, 20.5, fig. 20.5.1, fig. 20.7.1
spin axis inclination and accretional processes, 13.6
temperature profile and accretional processes, 12.10-12-11, fig.12.11.1
tidal deformation, table 9.2.1
satellites, absence of, 21.2
meteor streams
definition, 4.6

density, 14.3
orbital parameters, fig. 4.6.1
compared to jet streams, 14.2
formation and genetic relationships
accretional mechanism, 14.3
and comets, 4.6, 14.2-14.5,19.8
hetegonic model, 19.8, fig. 19.8.2, table 19.8.1
traditional view, 19.8, fig. 19.8.1
in transplanetary space, 19.3, 19.6, fig. 19.8.2
meteorites
definition, 4.1
composition
compared to composition of
Giacobinid meteors, 22.2
solar photosphere, 20.6, fig. 20.6.2
constituents
crystals, fig. 7.1.1, 22.3-22.4, fig. 22.3.1, 22.9
diamond, 11.8
hydrated minerals, 11.8
oxidized minerals, 11.8
noble gas content, 26.2
density, 14.2
as evidence of
accretion in separate jet streams, 22.6, 22.9
heating effects, 11.8, 22.4, 22.6
nongravitational accretion, 11.5
representative composition of planetesimals forming the Earth, 26.2
selection effects, 22.3
shock compaction and melting, 20.4
texture, 14.2, 22.3, fig. 22.3.1
interpretation of data
general discussion, 22.10
introduction of error due to assumption of
equilibrium condensation, 22.1
exploded planet hypothesis, 22.1
Laplacian disc, 22.1
irradiation record
compared to lunar surface irradiation, 22.9
cosmic ray tracks, fig. 22.9.1
hetegonic irradiation, 22.9
orbital history
asteroid belt as source, 22.2

collision history deduced from physical features, 22.6
as fragments of comets or near-Earth asteroids, 22.2
physical history (see also meteoroids)
summary, 22.8, fig. 22.8.1
age determinations, 22.9
as deduced from composition, 22.6
as fragments of
    asteroids, 22.2
    comets, 22.2
    exploded planet, 11.8, 22.1, 26.2
    precursor bodies, 22.2, 22.4
irradiation record, 22.9
thermal history, 11.8, 22.4
meteoroids
definition, 4.1, 4.6
formation and genetic relationships
hetegonic model, 19.8, fig. 19.8.2, table 19.8.1
origin from exploded planet, 11.8, 22.1, 26.2
as primeval matter in the solar system, 19.5
between short- and long-period meteoroids, 19.7, fig. 19.8.2
traditional model, 19.8, fig. 19.8.1
in transplanetary space, 19.6, fig. 19.8.2
meteors
    definition, 4.1
meteors, sporadic
definition, 4.6
formation and genetic relationships, 19.3
micrometeoroids (see also interplanetary dust; grains)
detection by Jupiter 10 flyby, 4.1, 4.3
forces governing orbital motion, 5.3-5.6, fig. 5.1.1
Mimas (see Saturnian satellite system)
Miranda (see Uranian satellite system)
models of solar system evolution
model development
general requirements, 1.1-1.2, 1.5
actualistic principle (see also actualistic princ
defined, 1.1
applications of, 1.1, 11.1, 11.7, 15.1, 15.4
hetegonic principle (see also hetegonic principle)
defined, 1.2
general characteristics, 16.9, fig. 16.9.1
applications of, 9.6, 20.7, 21.11, 22.1, 24.1, 25.1-25.5

specific models

gravitational collapse, 11.2, 21.1
hetegonic model (see also evolutionary stages)
brief synopsis, 16.6, fig. 16.6.1
characteristics of hetegonic plasma, 16.7
emplacement and ionization of infalling matter
critical velocity phenomenon, 21.2-21.5, 21.11 -21.13, figs. 21.2.1-21.2.2
emplacement of matter, 23.1-23.10
summary of preaccretional stages, fig. 16.7.1
partial corotation, 17.1-17.5
condensation, chs. 18-19
accretion, chs. 11-13
summary of accretional stages, fig. 18.10.1, 19.8, 19.8.2, table 19.8.1

Laplacian model (see also Laplacian-type models)
general description, 16.2
inadequacies, 2.4, 11.2, 16.2, 16.4, 20.1, 20.6-20.7, 21.1
planetesimal accretion (see also accretion, jet streams, grains)
introduction, 11.1-11.3
in jet streams, brief summary, 22.5
required properties of model, 11.7, 15.5
literature survey cited, 15.6
speculative element in models
in plasma physics and astrophysics, 15.3, fig. 15.4.2
introduced through postulates about the early Sun, 16. fig. 16.9.1
reduction of speculative element, 1.1, 1.5
modified Roche limit (see Roche limit, modified)
Moon
orbital parameters, table 2.1.3
orbital evolution
brief summary, 24.9
evidence of evolution from
lunar mare and basins, 24.6
remanent magnetization of lunar rocks, 24.5
tidal effects, 24.5, fig. 24.5.1
origin theories
method of choice among theories, 24.1
literature review cited, 24.1
accretion as satellite formation theory, 24.1
capture theory, 24.1, 24.4-24.5, figs. 24.4.1-24.4.2

supportive evidence for capture theory
lunar basins and mare, 24.6
lunar remanent magnetization, 24.5
variations of capture theory
close approach to Earth, 24.5
resonance modified orbit, 24.5
physical properties, table 2.1.3
composition
brief summary, 20.5, 24.9
crust, 24.7
loss of volatiles, 24.7
overlap of A and B clouds affecting composition, 24.8
surface features, 26.5
inclination of spin axis, 13.6
surface temperature, 24.7
temperature profile, processes affecting
accretion of planetesimals, 12.10-12.11, fig. 12.11.1
accretional hot spot front, 24.7
radiogenic heating of interior, 24.7
tidal deformation, table 9.2.1
motion, orbital (see orbital motion)
(N,a) diagram, fig. 4.3.3
orbital distribution of asteroids, 4.3
near-commensurability (see commensurability, near-)
nebula, Laplacian (see Laplacian-type models)
nebula, primeval (see Laplacian-type models)
nebulae from which planets and satellites formed (see nebulae, hetegonic)
nebulae, hetegonic (see also clouds (A, B, C, D))
defined, 16.7
general characteristics, 16.7
condensation of grains in nebulae, 16.5 (see also condensation)
heating during transfer of angular momentum from primary to secondary, 17.6
spacing between nebulae, 18.10
support by magnetic field of primary body, 16.4
negative diffusion
defined, 6.6, fig. 6.6.1
evidence from meteorites, 22.6
and formation of comets, 14.2
simple model, 6.7, fig. 6.7.1
neon, critical velocity of, 21.8
Neptune

orbital motion
orbital parameters, table 2.1.1
resonance with Pluto, 8.5, fig. 8.5.1, table 8.5.1
physical properties, table 2.1.1
mass, radius, density, table 20.5.1
composition, 20.5, figs. 20.5.2, 20.7.1
spin
inclination of spin axis, 13.6
tidal braking by satellites, 9.4
temperature profile, 12.10-12.11, fig. 12.11.1
tidal deformation, table 9.2.1
satellites (see Neptunian satellite system)
Neptunian satellite system (see also satellite systems; Triton)
absence of regular system
general discussion, 21.2, 24.3
orbital parameters, tables 2.1.2-2.1.3, fig. 24.4.1
physical properties, tables 2.1.2-2.1.3
mass distribution, 2.4-2.5
Pluto as former satellite, 8.5
Triton as captured satellite, 9.4, 24.4
Nereid (see Neptunian satellite system)
nickel
high content in rocks from upper mantle, 26.3, 20.5
noble gas content in meteorites compared to Earth's atmosphere, 26.2
nodes
described by guiding center approximation, 3.3
precession of, 3.3-3.6
nongravitational accretion (see accretion, nongravitational)
normal satellites (see Earth, satellites)
normalized distances
defined, 23.6
tabulated for planets and satellites, table 23.6.1
and information on the mass of the hetegonic Sun, 25.2
Oberon (see Uranian satellite system)
oblateness (see also tides)
    of bodies due to tidal effects, 9.2, table 9.2.1
    influence on motion of secondary bodies, 3.6
ocean, formation theories
summary, 26.7
accretional phenomena
introduction, 26.1
Earth's accretion

brief summary, 26.3, fig. 26.3.1
as affected by ocean and atmosphere, 26.4
planetesimals as source of ocean
hydroxyl content in meteorites, 26.2
noble gas content in meteorites, 26.2
reactive volatiles, 26.2
release of volatiles from impacting planetesimals, 26.3
retention of volatiles
in ocean, 26.4, fig. 26.3.1
in Earth's crust, 26.5
tidal effects due to Moon, 26.6
orbital angular momentum (see angular momentum, orbital)
orbital angular momentum, specific
    defined, 2.1
orbital angular momentum, total
    defined, 2.1
orbital distance, ratio of
defined, 2.2
and groups of secondary bodies, 2.5, table 2.5.1, 11.7, 18.10
and hetegonic processes
accretion, 11.7, 18.10
condensation, 17.5, 18.9
ionization of infalling gas, 21.4, 23.6
normalized distances, 23.6
of planets, table 2.1.1
of satellites, table 2.1.2
and Titius-Bode's law, 2.2, 2.6
and two-thirds law, 17.5, 18.9
orbital motion (see also semimajor axis; pericenter; nodes; eccentricity; inclination; orbital velocity; period)
    general treatments
        described by celestial mechanics, 5.1, fig. 5.1.1
        circular motion, 3.2
            with epicycles, 3.3, fig. 3.3.1
            motion of guiding center, 3.3
            with superimposed radial and axial oscillations, 3.3-3.7
        guiding center approximation of orbital motion
            definition, 3.1
            motivation, 3.1
            and apparent attraction, 6.4-6.5
            and eccentricity, inclination, pericenter and node, 3.3
            of gravitationally unperturbed motion, 3.4

with orbit of large eccentricity, 3.5
in perturbed gravitational field, 3.6-3.7
Kepler motion as motion of guiding center perturbed by oscillations, 3.1-3.7, fig. 3.3.1
plasma physics formalism, 5.1, 5.3-5.5
"proper elements", 4.3
governing forces and effects
summary, 5.6, fig. 5.1.1
accretional processes, 11.7, 18.11
collision effects, 6.3, 6.6-6.9
negative diffusion, 6.6, fig. 6.6.1
inelastic collisions, 6.6, fig. 6.6.1
and Kirkwood gaps, 8.6
supportive evidence, 22.6
condensation, 17.5, fig. 17.5.1
hydromagnetic effects
ionization and arrest of infalling gas, 21.4
transfer of angular momentum from primary to secondary body, 16.3
interplanetary medium, 6.2
limit between gravitational and electromagnetic dominance, 5.4
partial corotation
introduction, 17.1
compared to Kepler motion, table 17.3.1
transition from partial corotation to Kepler motion, 17.5
stability of orbital motion
introduction, 10.1
and asteroid belt, 10.3
and resonance structures, 10.2
and Saturnian rings, 10.3
orbital motion of populations of bodies
almost circular orbits (see planets; asteroids; satellite systems)
almost parabolic orbits (see comets, long-period; meteor streams; meteoroids)
elliptical orbits (see Apollo-Amor asteroids; comets, short-period; meteoroids)
large bodies (see planets; satellites)
small bodies (see small bodies)
orbital motion of specific bodies (see asteroids; comets; meteoroids; planets; satellite systems)
orbital period (see period, orbital)
orbital velocity
defined, 2.1
changes due to transfer of angular momentum from primary to secondary bodies, 16.1-

16.6, fig. 16.3.1
of planets, table 2.1.1
of satellites, tables 2.1.2-2.1.3
oxides, refractory
ratios of refractory oxides in meteorites, 22.9
oxides, transition metal
and gravitational differentiation, 12.13
oxygen
abundance in Earth, 20.5
critical velocity of, 21.8
oxidized minerals in meteorites, 11.8
parabolic, almost-, orbits/bodies (see comets, long-period; meteor streams; meteoroids)
parent bodies of meteorites (see precursor bodies)
partial corotation
definition, 17.1
characteristic orbital velocity derived, 17.2
energy considerations, 17.3
equilibrium conditions derived, 17.1-17.2
and Kepler motion
comparison, 17.3
transition between partial corotation and Kepler motion, 17.5
model for transfer of angular momentum from primary to secondary bodies
derivation, 16.3, fig. 16.3.1
modifications, 16.3-16.5
summary, 16.7
observational verification
asteroidal belt, 18.8
Saturnian rings, 18.6
summary, 18.9
and plasma in superprominences, 17.4
pericenter
described by guiding center approximation, 3.3
precession, 3.3-3.6
pericentric frictional heating mechanism (see also heating effects), 11.8, 21.12, 22.4
period, orbital (see also orbital motion)
asteroids, table 4.3.1
planets, table 2.1.1
satellites, tables 2.1.2-2.1.3
source of data for asteroids and comets cited, 4.1
period, spin (see also spin)

governing forces and effects
accretion processes, 13.6
resonances, 8.8
tidal braking, 9.1-9.6
isochronism of spins, 9.7, fig. 9.7.1, table 9.7.1, 10.4, 13.3-13.4
spin period for specific bodies
asteroids, table 4.3.1, table 9.7.1, fig. 9.7.1
Earth, prior to capture of Moon, 24.3
planets, 2.1, table 2.1.1
Sun, hetegonic, 16.2, 25.4, 25.6
Venus, 8.8, 13.6
Perseid meteor stream
association with comet P/Swift-Tuttle, 14.4
Perseid meteors
composition compared to that of chondritic meteorites, 22.2
Phobos (see Martian satellite system)
Phoebe (see Saturnian satellite system)
photosphere
composition compared to that of meteorites, 20.6, fig. 20.6.2
as example of cosmic plasma, 15.3
reliability of data, 20.6
physical properties of bodies (see asteroids; comets; meteoroids; planets; satellites)
pinch effects in plasmas, 15.3
planetesimal (see also embryo; fluffy aggregates)
defined, 1.4
planetesimal accretion (see also accretion, formation of embryo; models of solar system evolution)
defined, 12.1
applied to formation of ocean and Earth's atmosphere, 26.2-26.4
history of concept
general discussion, 11.3
literature survey cited, 11.3
supportive evidence
cratered surfaces of celestial bodies, 11.3, fig. 20.4.1, 24.6
meteorites, 11.3
spin acquisition theory, 13.3-13.4
spin isochronism, 11.3
planets (see also Mercury, Venus; Earth; Moon; Mars; Jupiter; Saturn; Uranus; Neptune; Triton; Pluto)
comparative studies (see comparative studies of planets/satellites)
formation and genetic relationships (see also evolutionary stages)

accretion
general treatment, 12.3-12.6
time required for accretion, 12.8-12.9, table 12.8.1, fig. 12.9.1
contraction of uniform disc, 21.1 (see also Laplacian-type models)
effects on evolution of the Sun, 25.6
gravitational collapse, 11.2, fig. 17.2.1, table 11.2.1
hetegonic model, 19.8, fig. 19.8.2, table 19.8.1
mass ejection from Sun, 21.1
mass infall toward the Sun, 21.1 (see also emplacement of matter)
traditional view, 19.8, fig. 19.8.1
groups of planets, 2.5, table 2.5.1, 23.5-23.6 (see also groups of secondary bodies)
orbital motion
forces governing, 5.1 5.2, fig. 5.1.1
orbital parameters, table 2.1.1
resonances, 8.5, table 8.5.1, 8.8
physical properties, table 2.1.1
composition, 20.5, table 20.5.1, fig. 20.5.1, fig. 20.7.1
mass distribution in planetary system, 2.4-2.5, 23.6
spin
inclination of spin axis, 13.6
spin-orbit resonances, 8.8
tidal braking by satellites, 9.4
temperature profile, 12.10-12.11, fig. 12.11.1
tidal deformation, table 9.2.1
planets, exploded (see exploded planet hypothesis)
planetology, comparative (see comparative studies of planets/satellites)
plasma, dusty (see also plasma, hetegonic)
electromagnetic effects, 5.3, fig. 5.1.1
plasma, hetegonic
general characteristics, 16.7
constituents, 16.7
densities, 16.5
heating/ionizing by currents, 15.1, 17.6, 23.1 23.4
processes active during hetegonic era (see also evolutionary stages)
brief synopsis, fig. 16.6.1, fig. 16.7.1
condensation (see condensation; kinematic image of condensing plasma)
interaction with neutral gas (see critical velocity phenomenon)
emplacement of matter (see emplacement of matter)
partial corotation (see partial corotation)
transfer of angular momentum from primary to secondary bodies (see angular momentum, transfer)

theoretical and experimental analyses, 15.2-15.5
plasma, pseudo
definition, 15.3
general characteristics, table 15.3.1
theoretical treatment, 15.3
plasma, real
general characteristics, 15.3, table 15.3.1
summary, 15.3, table 15.3.1
electrostatic double layers
experimental review cited, 15.3
properties, 15.3, fig. 15.3.1
filaments, pinch effect, 15.3, fig. 15.3.3
instabilities, 15.3
ionization
and critical velocity phenomenon, 15.3
degree of ionization, 15.3
magnetization
motion with respect to magnetic field lines, 15.3, fig. 15.3.4
relation of poloidal and toroidal fields, 15.3, fig. 15.3.3
low density regions, 15.3
theoretical treatment of, 15.3
plasma beam experiment on critical velocity, 21.8, figs. 21.8.6-21.8.8
plasma capture of transplanetary dust in hetegonic nebulae, 1.4
plasma cloud (see bands of secondary bodies; emplacement of matter; clouds (A, B, C, D))
plasma physics
application to
evolutionary theory, 1.4, 15.1, table 15.1.1, 15.6
space science, 1.4, 15.1, table 15.1.1, 15.2
studies of small bodies, 4.2, 5.2
experimental
Birkeland experiments, 15.2
configuration and process simulation, 15.3
relationship with theoretical plasma physics, 15.2
review of experimental work on the terrestrial magnetosphere cited, 15.3
theoretical
Chapman-Ferraro theory, 15.2
Chapman-Vestine theory, 15.2
and kinetic theory of nonionized gases, 15.2
and space missions, 15.2
and thermonuclear reactors, 15.2

treatment of pseudo plasma, 15.3, table 15.3.1
plasma physics formalism
treating orbital motion, 5.2
treating many-body problem, 5.2
plasma surrounding primary during formation of secondaries (see plasma,hetegonic)
platinum metals
high content in rocks from upper mantle, 26.3
Pluto (see also planets)
orbital motion
orbital parameters, table 2.1.1
resonance with Neptune, 8.5, fig. 8.5.1, table 8.5.1
as former satellite of Neptune, 8.5
physical properties, table 2.1.1
composition, 20.5, table 20.5.1, fig. 20.5.2, fig. 20.7.1
inclination of spin axis, 13.6
mass, radius, density, table 20.5.1
satellites
absence of, 21.2
plutonium
and gravitative differentiation, 12.13
polarization of grains in space (see electrostatic polarization)
populations of bodies (see orbital motion of populations of bodies)
potassium
and gravitative differentiation, 12.13
and loss from the Moon, 24.7
K/Ar ratios in meteorites, 22.9
potential, ionization (see ionization potential)
Poynting-Robertson effect
and orbital motion of interplanetary dust, 5.5, fig. 5.1.1
and resonance locking, 5.5
precursor bodies (see also meteoroids, formation)
defined, 11.8
accretion history
in jet stream environment, 22.5
nongravitational accretion, 22.7
electrostatic clustering, 22.7
magnetostatic clustering, 22.7, fig. 22.7.1
vapor condensation bonding, 22.7
summary, 22.8, fig. 22.8.1
physical history
size limit, 22.4

precursor material of celestial bodies and differentiation effects, 20.3
pressure, radiation (see radiation pressure)
primary body, properties during formation of secondary bodies
magnetic field, 16.1, 16.3, table 16.3.1
mass
and mass of satellite systems, 24.3, fig. 24.3.1
radiation
and composition of secondary bodies, 20.7
of early Sun, 25.5
spin
and formation of secondary bodies, 23.1-23.10
spin period and number of secondaries formed, 24.3, fig. 24.3.2
profile of a jet stream (see also jet stream)
defined, 4.3
asteroidal jet stream profile compared to hetegonic jet streams, 12.7
of Flora A, fig. 4.3.6
profiles, thermal (see temperature, profile)
prograde satellites (see also satellite systems)
listed, table 2.1.2
orbital characteristics, table 2.1.2
physical properties, table 2.1.2
prominences, solar (see also superprominences)
and information on hetegonic plasmas, 15.4
proper elements of orbital motion
defined, 4.3
and Hirayama families of asteroids, 4.3, fig. 4.3.5, table 4.3.2
periodic variation, 4.3, table 4.3.2
q-ratio (see orbital distance, ratio of)
radial distance ratios (see orbital distance, ratio of)
radiation, corpuscular (see also solar gale, solar wind)
acceleration of particles in hetegonic superprominences, 16.8
radiation, hetegonic
as recorded in meteorites, 22.9, fig. 22.9.1
during hetegonic era, 16.8, 5.5
radiation effects
effect on condensation processes, 20.7, 25.5
in meteorites, 22.9, fig. 22.9.1
on orbital motion, 5.5, fig. 5.1.1
radiation pressure
effect on motion of interplanetary dust, 5.5, fig. 5.1.1
radius

asteroids, table 4.3.1
of hetegonic Sun, 25.6
planets, table 2.1.1
satellites, tables 2.1.2-2.1.3
rare earth elements
and gravitative differentiation, 12.13
reactive volatiles
in crust and mantle rocks, 26.5
in Earth's planetesimals, 26.2
regular groups
definition, table 2.5.1
remanent magnetization
in lunar rocks and orbital evolution of the Moon, 24.5
in meteorites, 16.1
reservoirs, jet stream (see meteorites, composition)
resistive medium, 6.2
resonance
defined, 8.1
general discussion, 8.1
mechanisms for establishing resonanc
hetegonic effects, 8.1
tidal effects, 8.1
simple models
comparison of models, 8.3
pendulum, 8.2, fig. 8.2.1
primary with two satellites, 8.3,
types
near -commensurabilities
deviation from exact resonance, 8.4
transition to near-commensurability from resonance, 8.9
orbit-orbit resonance
general characteristics, 8.1, 8.5
Dione-Enceladus, 8.5, fig. 8.5.6, table 8.5.1
Earth-Toro, 8.5, fig. 8.5.2, table 8.5.1
Hildas-Jupiter, 8.5, fig. 8.5.4, table 8.5.1, 8.6
Io-Ganymede-Europa, 8.5
Pluto-Neptune, 8.5, fig. 8.5.1, table 8.5.1
Tethys-Mimas, 8.5, table 8.5.1
Thule-Jupiter, 8.5, table 8.5.1, 8.6
Titan-Hyperion, 8.5, fig. 8.5.5, table 8.5.1
Trojans-Jupiter, 4.5, 8.5, fig. 8.5.3, table 8.5.1
spin-orbit resonances

general characteristics, 8.1, 8.8
examples, table 8.1.1, 8.8
resonance, broken
and near-commensurabilities, 8.9
resonance capture (see resonance, mechanisms for establishing)
resonance effects
accretion processes
possible present-day examples, 11.6
and Kirkwood gaps, 4.3, 8.5, 8.6
compared to Saturnian rings, 18.6, figs. 18.6.1-18.6.2
and Poynting-Robertson effect, 5.5
and Saturnian rings, 8.7
and stability of orbits
general discussion, 10.2
tidal effects
Mercury, 9.5
satellites, 8.8, 9.6
Venus, 9.5
resonance locking (see resonance)
resonance, near-exact (see commensurabilities, near-)
retrograde satellites
defined, 2.3
and near-commensurabilities, 8.9
orbital parameters, table 2.1.3
radial distances, fig. 24.4.1
inclination of orbit, 24.4.1, fig. 24.4.1
physical properties, table 2.1.3
theory of retrograde satellite capture, 24.4
Rhea (see Saturnian satellite system)
rings, Saturnian (see Saturnian rings)
Roche limit
defined, 18.3
effect in Saturnian rings, 18.3
Roche limit, mod)fied
defined, 18.3
effect in Saturnian rings, 18.3-18.4
rotation, differential, of Sun (see Sun, hetegonic)
rubidium
in lunar rocks, 24.7
Rb^{87}/Sr^{87} ratios in meteorites, 22.9
runaway accretion (see accretion, runaway)
sand bank

as cometary nucleus, 14.3
satellite systems (see also Jovian, Martian, Neptunian, Saturnian, Uranian satellite systems; Earth, satellites)
comparative studies (see comparative studies of planets/satellites)
formation and genetic relationships
alternative explanations
infall of mass to planet (see also emplacement of matter), 21.1
ejection of mass from planet, 21.1
contraction of uniform disc (see also Laplacian-type models), 21.1
gravitational collapse, 11.2, fig. 11.2.1, table 11.2.1
capture of retrograde satellites, 24.4
as a function of g.avitational potential energy, 21.12, fig. 21.2.1
hetegonic model, 19.8, fig. 19.8.2, table 19.8.1
number of secondaries as a function of primary's period of rotation and mass, 23.1-23.7, 24.3, fig. 24.3.2
spatial limits of formation
Lagrangian point as outer orbital limit, 11.2, 21.2, fig. 21.2.1
synchronous orbit and inner orbital limit, 21.2, fig. 21.2.1, 23.9
theoretical prediction of formation, 23.8
absence of predicted satellites explained, 23.8-23.9
traditional view, 19.8, fig. 19.8.1
groups of satellites within one system
defined, 2.5
comparative studies of groups, 21.3
mass distribution within groups, 21.3
orbital motion
forces governing, 5.1
resonances, 8.5, table 8.5.1, 8.8-8.9
tidal effects, 9.6
orbital parameters, tables 2.1.2 2.1.3
physical properties, tables 2.1.2-2.1.3
composition, 20.5, table 20.5.1, fig. 20.7.1
mass distribution, 2.4-2.5, figs. 2.5.2 2.5.4, 23.6, fig. 23.6.1
mass as a function of primary's mass, 24.3, fig. 24.3.1
photograph of Phobos, fig. 20.4.1
tidal deformation, table 9.2.1
satellites, retrograde (see retrograde satellites)
satellites, synchronous (see synchronous satellites)
Saturn
orbital parameters, table 2.1.1
physical properties, table 2.1.1

composition, 20.5, fig. 20.5.2, table 20.5.1, fig. 20.7.1
mass, radius, density, table 20.5.1
spin
inclination of axis, 13.6
tidal braking by satellites, 9.4
temperature profile, 12.10-12.11, fig. 12.11.1
tidal deformation, table 9.2.1
satellites (see Saturnian satellite system)
Saturnian rings
accretion
assimilation of condensed grains, 18.5
collision within rings, 18.5
inside rings, 18.4
outside rings, 18.4
structure
described, 18.6
absence of resonance effects, 8.7
compared to structure of asteroidal main belt, 18.8
explanatory theories
hetegonic theory, 18.6, figs. 18.6.3-18.6.4
resonance theory, 18.6, fig. 18.6.1, 8.7
stability of structure, 10.3
tidal effects
effect of modified Roche limit, 18.3-18.4
effect of Roche limit, 18.3
Saturnian satellite system (see also satellite systems; Saturnian rings)
groups of satellites (see also groups of secondary bodies)
compared to other groups in same gravitational potential energy band, 21.3
introduced, 2.5
mass distribution within a group, 23.6-23.7
orbital motion
angular momentum, 2.4, fig. 2.3.3
capture of retrograde satellite Phoebe, 24.4
orbital parameters, tables 2.1.2-2.1.3
resonances
Dione-Enceladus, 8.5, fig. 8.5.6, table 8.5.1
Hyperion-Titan, 8.5, fig. 8.5.5, table 8.5.1
suggested resonances with rings, 8.7, 18.6, fig. 18.6.1
physical properties, tables 2.1.2-2.1.3
density, 20.5, table 20.5.1, fig. 20.7.1
mass distribution among satellites, 2.4-2.5, fig. 2.5.4, 23.6, fig. 23.6.1

second approach (see plasma, real)
self-gravitation
 and gravitational collapse of a gas cloud, 11.2, 21.1
semimajor axis (see also orbital motion)
 defined, 2.1
 asteroids, table 4.3.1, 4.3, 4.4, fig. 4.3.3
 planets, table 2.1.1, table 20.5.1
 satellites, tables 2.1.2-2.1.3, table 20.5.1
silicates
 as components of Earth's core, 20.5
 and gravitative differentiation, 12.13
size spectra, 7.2
small bodies (see also asteroids; comets; grains; meteoroids; Saturnian rings)
 classification, 4.1
 general characteristics
  composition
   of fluffy material, 20.4, 22.8, fig. 22.8.1
   effects of shock compaction, 20.4
  spectra
   cross-section, 7.2, table 7.2.1
   mass, 7.2, table 7.2.1
   radius, 7.2, table 7.2.1
   visual magnitude, 7.2, table 7.2.1
 evolution and development of small body populations
  by fragmentation and accretion, 4.1, 7.1, 7.3-7.4, 22.8, fig. 22.8.1
  motivation for studying, 4.1, 18.7, 22.1, 22.10
 orbital motion
  governing forces, 5.1-5.6, fig. 5.1.1
   collisions, 6.3, 18.2, 18.5
   partial corotation, 17.1, 18.2
  orbital parameters, 4.1, 4.3-4.4, table 4.3.1, figs. 4.3.1-4.3.4, 4.6, fig. 4.6.1
sodium emission from comets, 22.2
solar gale
 during hetegonic era, 5.5
 inadequate evidence in radiation records, 16.2, 25.4-25.5
 suggested analogy with T-Tauri phenomena, 16.2
solar magnetograms
 and solar composition, 20.6
solar nebulae
 composition compared to that of the solar photosphere, 20.6

solar photosphere
composition as model for "cosmic abundance", 20.1
solar radiation (see Poynting-Robertson effect; radiation pressure; solar gale; solar wind; Sun, hetegonic)
solar tides (see Sun, tidal deformation)
solar wind
braking of solar spin, 16.2
effect on orbital motion of interplanetary grains, 5.5
during hetegonic era, 25.5
source cloud
defined, 21.4, 21.11
general characteristics, 21.4, 21.11
composition compared to that of clouds (A, B, C, D), 21.12
and hetegonic processes, fig. 16.9.1
patterns of gas infall from source clouds, 21.12, figs. 21.12.1-21.12.2
for satellite systems, 21.4, fig. 21.4.1
spacing of celestial bodies (see bands of secondary bodies; groups of secondary bodies)
spallation products of cosmic rays
exposure age of meteorites, 22.9
speculation, reduction of (see models of solar system evolution, speculative element)
spin (see also isochronism of spins)
model of acquisition of rotation during accretion, 13.1-13-6
as a function of
density, 13.4
mass, 9.7, fig. 9.7.1, table 9.7.1, 13.3
size, 13.3
gravitational accretion, 13.3
inclination of spin axis, 13.6
nongravitational accretion, 13.2
post-accretional changes
energy dissipation, 9.3
spin of primary and satellite formation, 1.2, 23.1-23.8
braking of primary spin during angular momentum transfer to secondary body, 16.3, fig. 16.3.1
tidal effects, 9.1-9.6
spin, similarity of spin among celestial bodies (see isochronism of spins)
spin period (see period, spin)
sporadic meteors (see meteors, sporadic)
stability of orbits
introduced, 10.1

reconstructing hetegonic processes, 10.5, 18.6, 18.8
supportive evidence
asteroid belt, 4.2, 10.2
isochronism of spins, 10.4
resonance structures, 10.2
Saturnian rings, 10.3
stars, formation of
    by gravitational collapse, 11.2
    by stellesimal accretion, 25.7
statistical accretion (see accretion, statistical)
stellesimal accretion, 25.7
streams (see jet streams; meteor streams)
strontium
    in lunar rocks, 24.7
    Rb^{87}/Sr^{97} ratios in meteorites, 22.9
subvisual asteroids
    forces governing motion, 5.1-5.4, fig. 5.1.1
    influence on accretion in asteroid belt, 4.3, 6.3, 7.1, 7.3, 14.7, 18.2
    mass distribution, 4.1
sulfides
    and gravitative differentiation, 12.13
Sun
    characteristics during hetegonic era (see Sun, hetegonic)
    composition inferred from
        solar photospheric abundance data, 20.6
        solar radiation, 20.6
        spectrometric analysis, 20.6, fig. 20.6.1
    tidal deformation due to planets, table 9.2.1
Sun, hetegonic
    early characteristics of Sun are uncertain, 16.2, 16.9
    evolution
        during deuterium burning phase, 25.6, fig. 25.6.1, fig. 25.6.3
        during planetary formation, 25.6, figs. 25.6.2-25.6.3
        possible formation by accretion, 25.7
    magnetic field as deduced from
        hydromagnetic effects in planetary formation, 25.3
        transfer of angular momentum requirements, 16.1, 16.3, tables 16.3.1 16.3.2
    mass as inferred from
        normalized distances of the planets, 25.2
        structure of the bands of secondary bodies, 25.2
    radiation

corpuscular, 25.5
thermal, 25.5
radius
contraction during deuterium-burning phase, 25.6, fig. 25.6.1, fig. 25.6.3
spin period (see also angular momentum transfer)
braking by solar wind, 16.2
deduced from T_{ion}/τ values of the planets, 25.4
differential rotation, 25.4
changes during angular momentum transfer to Jupiter, 25.6, fig. 25.6.2
changes during contraction at the end of deuterium-burning phase, 25.6, fig. 25.6.1, fig. 25.6.3
sunspots
and information about hetegonic plasmas, 15.4, fig. 15
super corona
defined, 16.7
general characteristics, 16.7, fig. 16.6.1
superprominences (see also plasma, hetegonic)
defined, 16.6
general characteristics, 16.7, fig. 16.6.1
acceleration of particles, 16.8
effect upon emplacement of matter, 23.2
and partial corotation of plasma, 17.4
Swift-Tuttle comet, 14.4
synchronous planet
defined, 2.3
orbital parameters, table 2.1.1
synchronous radius of orbit
defined, 23.9
natural limit of satellite formation, 21.2
modifications, 23.9
apparent exceptions to rule, 23.9
Phobos, 23.9
Saturnian rings, 23.9
synchronous satellites
defined, 2.3, 8.8
orbital parameters, table 2.1.2
spin-orbit resonance, 8.8
T-Tauri stars, 16.2
T_{ion}/τ
defined, 23.1
change due to satellite formation, 23.4

chosen for each group of secondary bodies, 23.5
and mass distribution of secondary bodies formed, 23.6-23.7
and number of secondary bodies formed, 23.8-23.9, 24.3, fig. 24.3.1
and spin period of hetegonic Sun, 25.4

T_K/τ

defined, 23.5
for groups of secondary bodies, 23.5, fig. 23.5.1

tail, cometary, 4.1

Tellurian satellite system (see Earth, satellites)

temperature
of condensing grains and surrounding medium, 15.3, 22.1
hot spot front, 12.12-12.13
temperature profile
accretional effects, 12.10-12.11, fig. 12.11.1, 20.5
magnetic effects, 20.5

Temple-Tuttle comet, 14.4

Tethys (see Saturnian satellite system)

thermonuclear reactors
and experiments on critical velocity, 21.8
and relationship between experimental and theoretical plasma physics, 15.2

thorium and gravitative differentiation, 12.13
in lunar surface rocks, 24.7
U-Th/He ratios in meteorites, 22.9

Thule (see also asteroids)
and accretion processes, 11.6
association with Hilda asteroids, 4.4
Thule-Jupiter resonance
general characteristics, 8.5, table 8.5.1
and Kirkwood gaps, 8.6

tidal braking
of central body's spin, 9.3
of planetary spin by
satellites, 9.4
Sun, 9.5

tidal deformation
amplitudes of tides, 9.2, table 9.2.1
displacement of tidal bulge, 9.3, fig.9.3.1
and energy dissipation, 9.3
oblateness of bodies, 9.2, table 9.2.1

tidal effects
on evolution of ocean and atmosphere, 26.6
on satellite orbits, 3.6, 9.6

and self-gravitation, 18.3
on spin of celestial bodies, 9.1-9.6
tides
amplitude, 9.2, table 9.2.1
Laplacian theory of terrestrial tides, fig. 9.4.1
phase relations of terrestrial tides, 9.4, fig. 9.4.1
producing changes in spin, 9.3-9.6
time (duration) of infall of matter
defined, 12.8
value chosen, 12.10
time required for embryo growth
to infinite radius
defined, 12.3
and embryo growth, 12.6, fig. 12.6.1
numerical values for planets, 12.8-12.9, table 12.8.1
to reach runaway accretion
defined, 12.6
and embryo growth, 12.6, fig. 12.6.1
numerical values for the planets, 12.8-12.9, table 12.8.1
and resulting temperature profile, 12.10
time of escape, 2.2
Titan (see Saturnian satellite system)
Titania (see Uranian satellite system)
Titius-Bode's law
defined, 2.6
inadequacies, 2.6
Toro (see also asteroids)
Earth-Toro resonance, 8.5, fig. 8.5.2, table 8.5.1
transplanetary condensation (see condensation, transplanetary)
transplanetary jet streams (see jet streams, types)
transplanetary magnetic field
defined, 19.2
compared to galactic magnetic field, 19.2
transplanetary region
defined, 19.2
trapped infalling gas (see clouds (A, B, C, D))
trapped resonance (see resonance)
trigger element (see element, dominant/controlling)
Triton (see also Neptunian satellite system)
orbital motion
forces governing 5.1-5.2, fig. 5.1.1

orbital evolution as a captured satellite, 24.4
orbital parameters, table 2.1.3, fig. 24.4.1
physical properties, table 2.1.3
composition, 20.5, table 20.5.1, fig. 20.5.2
mass, radius, density, table 20.5.1
tidal deformation, table 9.2.1
Trojan asteroids (see also asteroids)
general discussion, 4.5, 8.5
and accretion processes, 11.6
orbiting in Jovian Lagrangian points, 4.5
as remnants of Jovian accretion, 4.5
resonance with Jupiter
general characteristics, 8.5, fig. 8.5.3, table 8.5.1
relation to retrograde Jovian satellites, 8.5
semimajor axes, fig. 4.3.3
two-body problem in celestial mechanics, 5.2
two-thirds fall-down ratio (see two-thirds law)
two-thirds law
defined, 17.5
derived, 17.5
and condensation from a corotating plasma, 17.5, fig. 17.5.1
observational verification, 18.9
in asteroidal belt, 18.8, fig. 18.8.1
in Saturnian rings, 18.6, figs. 18.6.3-18.6.4
Umbriel (see Uranian satellite system)
uniform disc of primeval matter (see Laplacian-type models)
Uranian satellite system (see also satellite systems)
groups of satellites
defined, 2.5
comparative studies, 21.3
mass distribution within groups, 23.6-23.7
orbital parameters, table 2.1.2
angular momentum, fig. 2.3.4
physical properties, table 2.1.2
compared to other bodies in same gravitational potential energy band, 21.3
mass distribution, 2.4-2.5, fig. 2.5.3
uranium
and gravitative differentiation, 12.13
in lunar surface rocks, 20.5
U-Th/He ratios in meteorites, 22.9
Uranus
orbital parameters, table 2.1.1

physical properties
composition, 20.5, table 20.5.1, fig. 20.5.2, fig. 20.7.1
mass, radius, density, table 20.5.1
spin
inclination of spin axis, 13.6
tidal braking by satellites, 9.4
temperature profile
and accretional processes, 12.10-12.11, fig. 12.11.1
satellites (see Uranian satellite system)
vaporization, selective
in laboratory experiments, 21.12
on Moon, 21.12
of transplanetary condensates in plasma clouds, 21.12
velocity, collision (see collisions)
velocity, internal (see also accretion; fragmentation; negative diffusion)
of jet stream
defined, 12.2
influence on accretion and fragmentation, 7.4, 12.3, 22.5
velocity, ionization (see ionization velocity)
velocity, relative (see velocity, internal)
velocity of infall (see infall velocity, critical velocity)
Venus (see also planets)
orbital motion
orbital parameters, table 2.1.1
spin-orbit resonance, 8.8
physical properties, table 2.1.1
composition, 20.5, table 20.5.1, figs. 20.5.1,20.7.1
spin
inclination of spin axis, 13.6
retrograde spin and accretional processes, 13.6
surface features, 20.5
temperature profile and accretional processes, 12.10-12.11, 12.11.1
tidal deformation, table 9.2.1
satellites
absence of satellites explained, 21.2
vertical mixing
of volatiles in crustal and upper mantle rocks, 26.5
Vesta (see also asteroids)
composition, 20.5
mass, radius, density, table 20.5.1
spin period, table 9.7.1
surface features, 20.5

visual magnitude, table 9.7.1
virial theorem
and gravitational collapse, 11.2
viscosity (see apparent attraction; collisions; Kepler motion, perturbed)
visual magnitude
of asteroids, table 9.7.1
spectra among group of bodies, 7.2, table 7.2.1
volatiles
accretion in jet streams
brief discussion, 16.7
compared to accretion of solids, 6.6, 12.3, 18.11
content in
lunar surface rocks, 26.5
meteorites, 26.2
as dissipative medium in jet stream
supportive evidence from meteorites, 18.11
in hetegonic plasma, 16.3
loss from Earth and Moon during accretion, 24.7
evidence for accretional hot spot front, 24.7
processes affecting
frothing, 24.7
convection, 24.7
gas scavenging, 24.7
release from impacting planetesimals, 26.2-26.3
retention in atmosphere during Earth's accretion, 26.4
and transfer of angular momentum from primary to secondary bodies,16.3
volatiles, reactive
in Earth's planetesimals, 26.2
voltage, burning
in magnetic fields
and critical velocity phenomenon, 21.8
voltage, limiting
of burning voltage in magnetic fields
and critical velocity phenomenon, 21.8
water
emission from comets, 14.6
and hot spot front, 26.4
released from impacting planetesimals to form terrestrial ocean and atmosphere, 26.4, fig. 26.3.1
xenon
I^{129}/Xe^{129} ratios in meteorites, 22.9

INDEX PAGE