N. A. Rynin

INTERPLANETARY FLIGHT AND COMMUNICATION

Volume III, No. 9

ASTRONAVIGATION
Theory, Annals, Bibliography
Index

TRANSLATED FROM RUSSIAN

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(Mezhplanetnye soobshcheniya)

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Theory, Annals, Bibliography
(Astronavigatsiya, letopis' i bibliografiya)

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Table of Contents

FOREWORD TO ISSUE NO.9

This is the ninth (and last) independent issue in a series of publications prepared by the author under the general title of Interplanetary Flight and Communication.

The previous eight issues in this series include the following titles:

Issue No. 1: Dreams, Legends, and Early Fantasies, Leningrad 1928.
" No. 2: Spacecraft in Science Fiction, Leningrad 1928.
" No. 3: Radiant Energy: Science Fiction and Scientific Projects, Leningrad 1931.
" No. 4: Rockets, Leningrad 1929.
" No. 5: Theory of Rocket Propulsion, Leningrad 1929.
" No. 6: Superaviation and Superartillery, Leningrad 1929.
" No. 7: K. E. Tsiolkovskii: Life, Writings, and Rockets, Leningrad 1931.
" No. 8: Theory of Space Flight, Leningrad 1932.

Readers' comments and requests for back issues should be directed directly to the author,

Nikolai Alekseevich Rynin
Leningrad, ul. Zhukovskogo No. 4, apt. 9

A supplement to this last issue includes the tables of contents of all the previous issues. There is, moreover, a limited number of sets available, mainly for library use, with the nine issues bound in three volumes.

N. Rynin

Leningrad, 1 March 1932

2 GENERAL FOREWORD TO THE NINE ISSUES

Despite considerable difficulties, we have succeeded in bringing to completion the publication of the nine issues in the series Interplanetary Flight and Communication in Science Fiction and in Scientific Projects, first launched in 1927.

The nine issues published during the five-year period 1927—1932 include the following titles:

1. Dreams, Legends, and Early Fantasies
2. Spacecraft in Science Fiction
3. Radiant Energy: Science Fiction and Scientific Projects
4. Rockets
5. Theory of Rocket Propulsion
6. Superaviation and Superartillery
7. K. E. Tsiolkovskii: Life, Writings, and Rockets
8. Theory of Space Flight
9. Astronavigation: Theory, Annals, Bibliography*

Upon completion of this lengthy project, I would like to share with my readers those impressions which crystallized in the course of my work on the various problems of interplanetary travel in general and rocket propulsion in particular. I can say, without the risk of exaggeration, that whereas in terms of transportation our epoch is the epoch of aviation and aircraft, the next epoch will be the epoch of rocket missiles which will transport with tremendous velocities various instruments, mail, cargo, and eventually passengers within the reaches of the stratosphere.

In 1927, when the publication of this series began, a fairly comprehensive theory of rocket propulsion was available, but these were mere vestiges of a practical approach to the solution of the entire problem. Now, five years later, valuable results of laboratory tests of rocket engines are available, and some tests have been made with the application of rocket propulsion to railway trolleys, sledges, automobiles, and airplanes. Small rockets have actually been launched in test flights, and similar experiments are planned with progressively larger rockets for the near future. The
3 results of these tests and experiments have aroused considerable interest in military circles in various countries, and the application of rockets to the propulsion of weapons is now being investigated. Eventually, this may lead to rocket-propelled artillery. Rockets are also being tried for assisting airplane takeoff.

* In addition to these publications, H. Oberth's "Wege zur Raumschiffahrt" was translated into Russian from the third German edition and submitted to the publisher (Gostekhizdat).

The idea of interplanetary travel is gradually being taken up by ever-increasing circles of people in various countries, where formal and informal study groups have been established. The American Interplanetary Society has been organized in the USA; in Germany, Der Verein für Raumschiffahrt is operating. In France, Le Comité d'Astronautique has been established, with the tradition of an annual prize award for the best treatise on interplanetary travel. In the USSR, the Society for Interplanetary Travel was organized in Moscow back in 1924, but unfortunately it ceased its activities in the same year. Numerous study groups among university students were temporarily organized during the years in various towns in the USSR, and especially in Leningrad, but because of shortage of funds, the complex problems involved, and pressing academic duties, these groups could not show intensive activity.

It is clear, however, that the topic of interplanetary travel is attracting increasing attention among both scientists and laymen in the USSR, as elsewhere, and the time has come for the establishment of a society for interplanetary travel under the auspices of a recognized scientific institute.*

An indication of this growing interest is provided by the establishment of "GIRD" (Gruppa po Izucheniyu Reaktivnogo Dvizheniya — Study Group for Rocket and Jet Propulsion) under the auspices of Osoviakhim (Soviet Society for the Advancement of Civil Defense and Aviation-Chemical Industry) in Moscow and Leningrad. The Moscow group is known simply as GIRD, whereas the Leningrad group is designated LENGIRD. Both groups have several hundred registered members.

A considerable volume of new material has accumulated in my files which was not included in the earlier issues. It will be used as part of the next issue, if I am lucky enough to see it through printing. At this juncture, I would like to acknowledge the great help of organizations and individuals who assisted me in my work on this series.

1. The Leningrad Transportation Engineering Institute, the publisher of Issue No. 5 in this series, "Theory of Rocket Propulsion."

2. N. Il'in, the official Leningrad representative of the Technical Division of the People's Commissariat of Armament, who was instrumental in obtaining permission for the publication of Issues Nos. 8 and 9.

3. G. V. Oppokov and N. V. Uittenkhoven of the editorial board of the Scientific and Technical Committee of the Artillery Corps of the Red Army, for permission to print the bibliography on rocket missiles.

4 4. P. P. Soikin, for publishing Issue No. 2 of the series, "Spacecraft in Science Fiction."

5. V. P. Glushko, for making available valuable material on the history of interplanetary travel in the USSR.

6. K.E.Tsiolkovskii, for kindly sending from Kaluga copies of his publications and for showing warm interest in our work.

7. G. Oberth, H. Hohmann, W. Ley, R. Esnault-Peltrie, R. Goddard, Lademann, and A. Scherschevsky for exceptional interest in my work and for kindly making available copies of their valuable work on interplanetary travel.

* The aims of such an organization are discussed in Issue No. 4, "Rockets."

8. Last but not least, the numerous (over 300) readers who took the trouble of writing to the author from remote parts of the USSR, supplying remarks and additions and often describing their own, valuable and interesting researches in the field of rocket propulsion and the history of interplanetary travel.

The results of my work are naturally far from perfect, but they represent the best of my poor efforts. May those better endowed continue after me!

N. Rynin

Leningrad, 1 March 1932

Author's address:

Nikolai Alekseevich Rynin
Leningrad, ul. Zhukovskogo No. 4, apt. 9

5 INTRODUCTION

This ninth (and last) issue of the series Interplanetary Flight and Communication is concerned with the description of the paths to be followed by the spacecraft of the future.

Some basic information in astronomy is first given, mainly with regard to the Earth, the Moon, and other planets of the solar system. Special charts of the apparent trajectories of the planets and of their orbit in orthogonal projection are shown. These charts clearly demonstrate the intricacies and complexities of astronavigation, i. e., navigation of spacecraft in outer space among the complex paths of planets and planetoids.

Some calculations relating to spacecraft navigation and velocities are given.

A general supplement to the entire series includes an annals and a bibliography of interplanetary travel and a name and subject index for all the nine issues.

7 *ASTRONAVIGATION*

Flight in Interplanetary Space

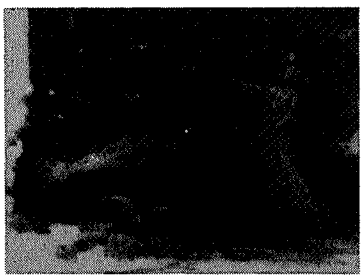


FIGURE 1. The flight of Flammarion with Urania among the stars

Oh Time! Destroying willfully everything in life,
Iron and diamonds alike, compared to ashes.
Only I am exempt from thy burden. To freedom,
Cleaving the crystal firmament of heaven with my wings,
I fly.... Above the spheres... The clear-eyed mind
Foresees a new and glorious world.

Giordano Bruno (sonnet)

It is conceivable, and therefore possible that man will eventually reach the farthest celestial bodies

Albert Einstein

Before proceeding with a detailed treatment of the problem of interplanetary travel, we have to be ready with clear answers to the following fundamental questions:

1. What are the distances to be traversed by interplanetary ships on their way to other planets ?
2. What planets, comets, or other celestial bodies can be encountered in interplanetary space and what are their dimensions ?
3. What are the movements of these objects ?
4. What is the effect of their gravitational pull on the interplanetary ship ?
5. What are the conditions of life on other planets ?

The present chapter will attempt to throw some light on these topics, but only in broad outline, as will prove quite sufficient for our purpose. Item 5 has been dealt with in detail in a previous issue "Spaceships in Science Fiction."

As an introduction to this chapter, we reproduce here the inspired description of the abysses of outer space from C. Flammarion's "Popular Astronomy."

FLIGHT IN OUTER SPACE

Our Earth is a globe which rushes, rolls, and spins like a tow with more than ten continuous and diverse motion components, but we are so minute

and so far removed from the other worlds that everything else appears
8 stationary and immutable in our eyes. And yet, the night spreads its gown, stars are lit in the depths of heaven, the "Evening Star" flashes in the West, the Moon suffuses the atmosphere with its bountiful glow.

Let us now take off with the speed of light (Figure 1).

In two seconds we will have passed the lunar world, with its yawning craters, rolling mountains, and dead valleys. We do not stop there. The Sun appears again; in its light we cast one last glance at the illuminated Earth, a small tilted sphere which progressively grows smaller and vanishes in the eternal night. Now another Earthlike planet appears, Venus, a world inhabited by swiftly and purposely moving creatures. Then we pass so close to the Sun that its frightening flares are clearly visible; we continue onward and onward. Here is Mars with its landlocked seas, bays, coasts, larger rivers, its people, strange cities, active and busy population. But time presses and we do not stop. Next is the tremendous giant, Jupiter. A thousand Earths are smaller than this giant. What speed in its life! What noise on its surface! What storms, volcanoes and hurricanes in its enormous atmosphere! What monsters in its waters! No human life has evolved as yet in this world... Onward and onward we fly. Here is another world which is as swift as Jupiter and is encircled by a mysterious glow; this is the fantastic planet Saturn with ten worlds presenting different aspects circling around it. No less fantastic are the creatures inhabiting these worlds.

We continue with our celestial flight. Uranus, Neptune,* the very last of the known worlds which we encounter on our way. We press onward and onward.

A pale, disheveled, quiet and tired comet glides in front of our eyes, lost in the night of its aphelion; the Sun still can be made out, an enourmous star glittering among the celestial population. Moving at a constant velocity of 300,000 km per second, it took us only four hours to cover the distance to Neptune. But now for a few days we have been flying through cometary
10 aphelia and will continue for a few weeks and months in our crossing of the starless emptiness surrounding the solar system; our only companions are comets which wander from one system to another, shooting stars, meteors, and fragments of dead worlds which have vanished from existence. We fly onward and onward for three years and six months, before we reach the nearest star, a majestic double luminary which pours out much more heat and light into the surrounding space than our Sun. We do not stop here either and continue with our journey for 10, 20, 100, 1,000 years, maintaining a constant speed of 300,000 km per second. We continue flying for 1,000 years without stopping, encountering on our way those complex systems, those new suns of various sizes, those powerful and bountiful furnaces whose light flares and dies; those innumerable constantly changing and growing planetary systems, distant worlds inhabited by unrecognizable creatures of a variety of forms and shapes, those multicolored satellites, and all those unexpected celestial views; we will observe celestial humanities, salute their efforts, achievements, their history, speculate on their morals, passions, ideas. And yet we will not stop! There is another thousand years of straight-line flight; we will flash through all these clusters of suns,

* The planet Pluto had not been discovered at the time of writing.

(9)

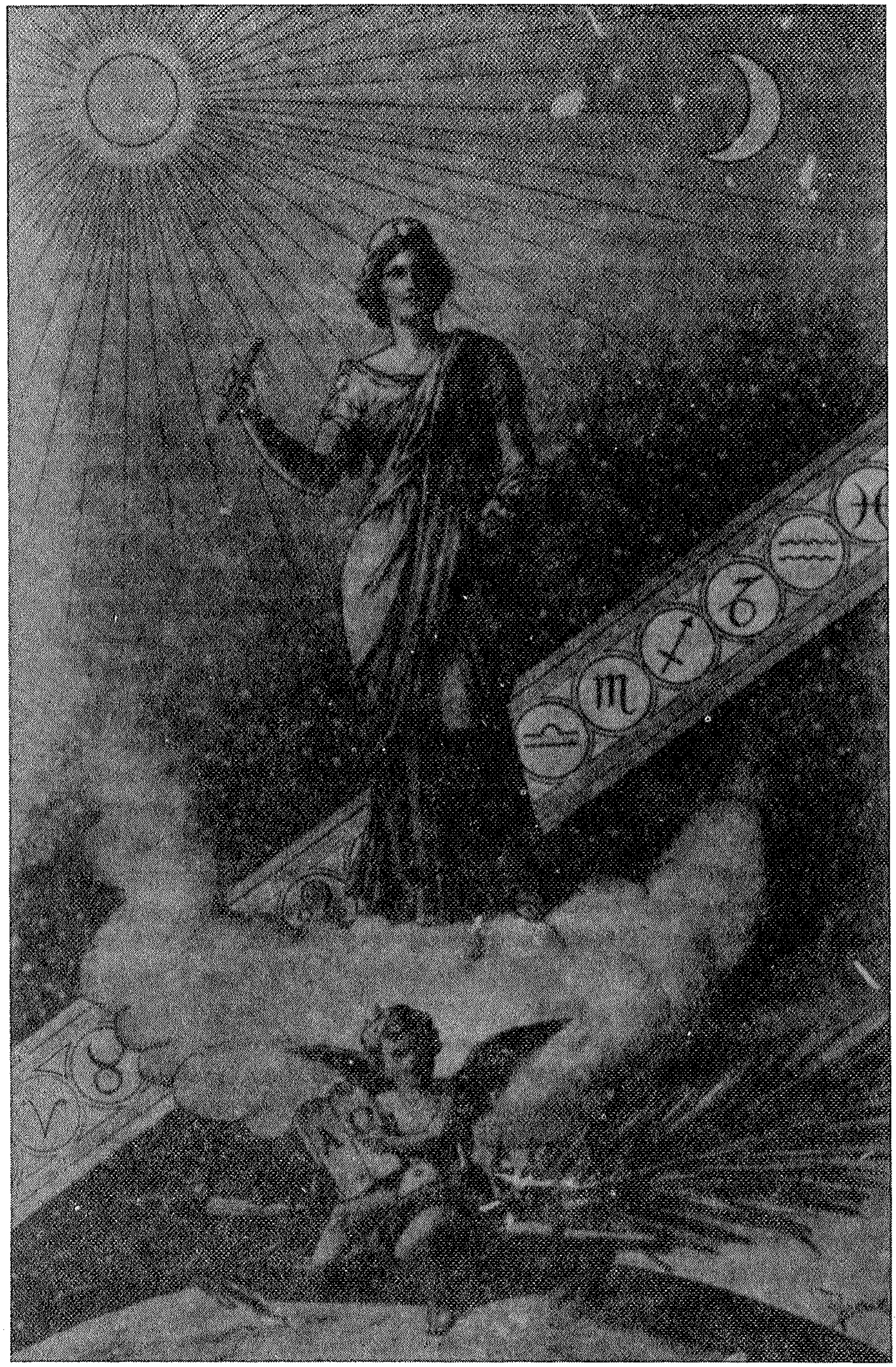


FIGURE 2. Urania, the Muse of Astronomy

through this Milky Way torn into nebulous patches, through a succession of these fiery life-sustaining furnaces which give way to the yawning abysses of space; we will not be surprised to see that approaching suns or the distant stars fall like rain before our eyes, like fiery tears vanishing for ever in a deep abyss; we will witness the collision of globes, the destruction of worlds, the creation of new planets; we will follow the fall of systems toward the beaconing constellations; and yet we will not stop! Another thousand years, another ten thousand years of steady flight, without stopping, tracing a straight line with a constant velocity of 300,000 km per second. Suppose that we have traveled in this way for a million years... Will we have reached the edge of the visible Universe? A dark abyss spreads before us, but new stars twinkle there in the depths of the sky. We will direct our flight to these stars and eventually reach them.. Another million years have passed: new experiences, new beautiful stars. New universes, new worlds, new earths, new humanities!.. And so on, without any end. When will the horizon close? Where is the firmament? Where is the sky to check our advance? Space and emptiness on all sides as before!.. Where are we now? How far have we advanced?.. We are at the threshold of infinity!.. We have not advanced a single step. We are still at the same point. The center is everywhere, the circumference is nowhere to be found... The endless abysses are again in front of us and we still have to explore them. We have not seen anything, we retreat frightened, crushed, unable to go on with the useless journey... We may keep falling and falling along a straight line into the dark abyss, fall to eternity, without ever reaching the bottom or the top... We are never any closer to it than we were before. The nadir turns into the zenith. There is no heaven and no hell, no east, no west, no north, and no south, there is no up and no down, no left and no right. Whatever way we turn, the Universe is infinity. In this infinity are scattered clusters of suns and worlds, making up our visible Universe, which is only one island in a gigantic archipelago. Compared to eternity, the life of our proud humanity, with its rich religious and political history, the life of our entire planet, is nothing more than a passing vision.*

ASTRONOMY

Let life torture us and every passing day
Cause anxiety by resounding bitter thoughts,
Sorrow treacherously gnawing at our mind;
Look up at the night sky,
Covered with starry dew,
Where the Milky Way, like a band,
Stretches multiplying light by light;
Look humbly at these marvels,
And eternity will gently destroy
In you those earthly voices,
Assuaging the sleepless memory
By a bandage of darkness placed across the eyes;
The tear will freeze, without dropping,
And the instant will pass in infinity!
The holy infinity heals
All pain, all greediness, all rebelliousness,
Firmly curbing hopelessness
By giving hope of other being!
Night, without melting the secrets of creation,
The light of innumerable stars streaming,
Announces the existence, near us,
Of other worlds, of lands
Where love and feeling are also known,
Where life and death are shared by all!
It announces that the sky is a frontier
O planetary spheres, that the distance is a track,
That the suns and our "ego"
Attract us inevitably into space.

V. Bryusov, "Golos inykh mirov" ["The Voice of Other Worlds"]

* According to Einstein's theory, the Universe is infinite but bounded, with a radius of curvature of 170 million light years.

THE MOTION OF CELESTIAL BODIES

THE EARTH IN SPACE

THE EARTH*

The wandering Earth, propelled by primeval forces,
Are you alive or a lump of inanimate matter ?
    Spin, strive, fate does not wait!
    Rotation after rotation,
    Day after day, year after year,
    Century after century, forward and forward !
    Fly forward, fate does not wait !
A flying seed ! An undeveloped embryo !
The empty shell of an unfertile egg !
A green apricot knocked by thunderstorm from the branch !
By no means an emerald in the celestial ring !
    Spin, strive, fate does not wait !
    Rotation after rotation !
Miserable fly in the Sun's cobwebs,
A single grape from the celestial vine,
The Earth, abandoned between the planets, in the emptiness,
Dancing its circular jig without end.
    Day after day, year after year,
    Fly forward, forward !
A tiny dot, unsupported in space,
A dot without its i ! A round float
Swinging on the ocean waves which
Sinks to the bottom, when the time comes !
    Spin, Earth ! Fate does not wait !
    Rotation after rotation !
A bowling ball, thrown by an inexpert hand !
A lump of dirt from the compressed fists of the Creator !
Somebody's dark brain, without the cranium, uninvited,
Wandering endlessly between the stars in space !
    Spin, spin, fate does not wait !
    Rotation after rotation,
    Day after day, year after year,
    Century after century, forward, forward,
    Fly forward, fate does not wait !

René Arcas

* [Original not available. Verbatim translation from the Russian.]

13 Our planet Earth, which in our imagination serves as the point of departure for flights to other worlds, is a nearly spherical object moving through the Universe (Figure 3). Its motion is highly involved, being governed by a variety of forces. Let us consider the main components of the Earth's motion.

First motion. Axial rotation.

The table lists the rotation velocities of the Earth, in m/sec, at various latitudes:

Latitude	Rotation velocity, m/sec	Latitude	Rotation velocity, m/sec
0° (Equator)	465	50	300
10	458	60	234
20	437	70	160
30	403	80	81
40	357	90° (Pole)	0

Second motion. Orbital revolution around the Sun. Figure 4 shows the
path, or the orbit, traced by the Earth around the Sun in one year. This
14 orbit is an ellipse, with the Sun at one of its foci. The line joining the
perihelion (the point where the Earth is closest to the Sun in its orbit) with
the aphelion (the Earth's position farthest from the Sun) is known as the
line of apsides. In September and March, on certain dates, the length of
the day is equal to the length of the night: the vernal equinox falls on
21 March and the autumnal equinox on 23 September. In winter, the shortest
day occurs on 21 December, the date of the winter solstice. In summer,
21 June is the longest day, the summer solstice. The line between the
winter and summer solstices of the orbit is known as the line of solstices
(or solstitial line). The line of equinoxes (or equinoctial line) joins the
vernal and autumnal equinoxes in the orbit.

FIGURE 3. The Earth moving through space

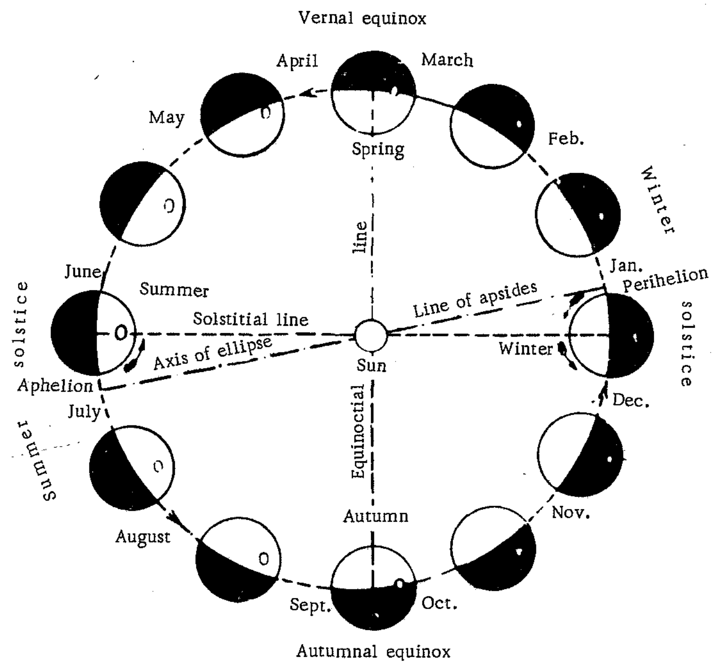


FIGURE 4. The Earth's orbit

The plane of the Earth's orbit, when continued in all directions, will
cross the celestial sphere along a curve known as the ecliptic (Figure 5).
Marking the position of the Earth in the orbit at monthly intervals, we
draw lines through these points and the Sun to their intersection with the
ecliptic. These intersection points correspond to the projections of the
Sun onto the sky for different positions of the Earth in its orbit. On
21 March, the Sun is projected onto the point γ of the ecliptic (the point
of the vernal equinox), on 21 June it is projected onto the point of the
summer solstice M, on 23 September onto the point of the autumnal
15 equinox γ', and on 21 December onto the point of the winter solstice M',
etc. Certain constellations are observed in the sky near each of these
projection points. The 12 constellations corresponding to the 12 months
of the year are known as the **signs of the zodiac**. The signs of the zodiac
are listed in Table 1, which also gives their astronomical notation.

A colorful description of Phaeton, Apollo's son, riding in his father's
fiery chariot through the signs of the zodiac is found in Ovid's Meta-
16 morphoses (Book II): "Now too, in his fright, he sees all parts of the
heavens filled with objects of horror, and the monstrous forms of huge
wild beasts."

(15) TABLE 1. Signs of the zodiac

No.	Constellation		Month when sun is in constellation	Sign of the zodiac	Origin of the sign (according to Flammarion)
	Latin name	English name			
1	Aries	Ram	May	♈	Horns of the ram
2	Taurus	Bull	June	♉	Bull's head
3	Gemini	Twins	July	♊	Twins
4	Cancer	Crab	August	♋	Reciprocating motion
5	Leo	Lion	September	♌	Lion's tail
6	Virgo	Virgin	October	♍	Virgin and 2 women carrying stalk of grain
7	Libra	Scales	November	♎	Scales
8	Scorpio (or Scorpius)	Scorpion	December	♏	Legs and tail of a scorpion
9	Sagittarius (or Arcitenens)	Archer	January	→	Arrow
10	Capricornus (or Caper)	Goat	February	♑	Horns and tail of a horned animal
11	Aquarius (or Amphora)	Waterman	March	♒	Waves
12	Pisces	Fish	April	♓	Two fishes spine to spine

A Latin rhyme is used as a mnemonic, listing the signs of the zodiac from the point of the vernal equinox:

Sunt: Aries, Taurus, Gemini, Cancer, Leo, Virgo,
Libraque, Scorpius, Arcitenens. Caper, Amphora, Pisces.

In April—May, the Sun is projected between Aries and Taurus, in November—December between Scorpio and Sagittarius, etc. There is a similar poem in Russian, listing the signs of the zodiac:

Овен идет перед Тельцом,
За Близнецами — Рак,
Лев перед Девою идет,
Последний летний знак.
С собою холода несут
Весы и Скорпион с Стрельцом
Поля морозит Козерог,
А Водолей сковал Рыб льдом.

Verbatim translation follows:

Aries precedes Taurus,
Cancer follows Gemini,
Leo precedes Virgo,
The last of the summer Signs.
The winter cold is brought by
Libra and by Scorpio with Sagittarius.
Capricorn covers the fields with frost
And Aquarius has chained Pisces in ice.

17 The line passing through the center of the Sun parallel to the Earth's axis of rotation crosses the celestial sphere at two points known as the celestial poles: the North Pole P and the South Pole P'. Since the Earth's orbit is pitifully small compared with the distances to the nearest stars, it is assumed that the Earth's orbit points to the same poles irrespective of the particular position on the Earth in its orbit.

The line PP' is known as the axis of the celestial sphere.

The plane through the center of the Sun, perpendicular to the axis of the celestial sphere, crosses the sky along a circle known as the celestial equator. The line of intersection of the plane of the equator and the ecliptic is the line of equinoxes $\gamma\gamma'$. Again, because of the small dimensions of the Earth's orbit, it is assumed that the plane of the terrestrial equator always coincides with the plane of the celestial equator. The angle between the equatorial plane and the plane of the ecliptic is 23.5°. The line through the center of the Sun, perpendicular to the plane of the ecliptic, meets the celestial sphere at two points known as the poles of the ecliptic: the North Pole T and the South Pole T'.

(16)

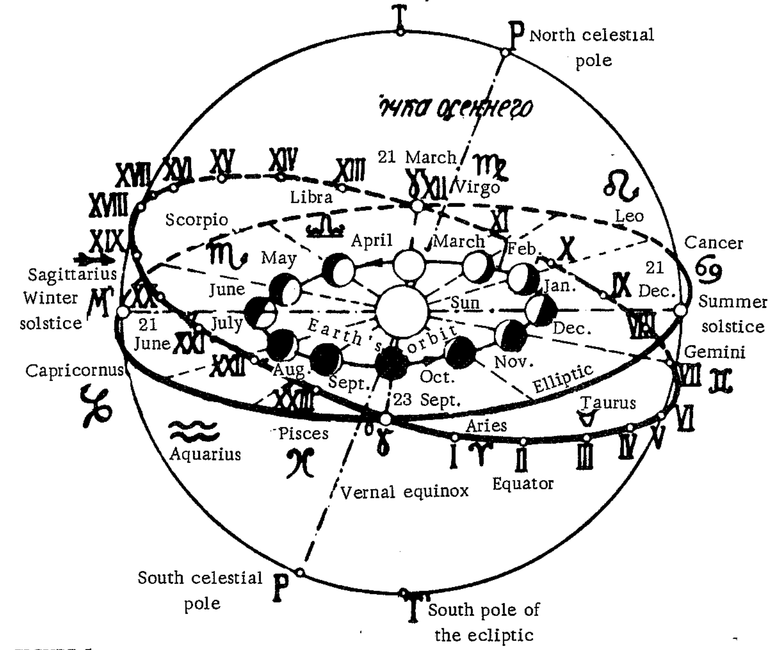


FIGURE 5.

For convenience, the celestial equator is divided into 24 parts of 15° each, starting with the point of the vernal equinox γ and going in the northward direction (I, II, III, . . . , XXIV in Figure 5). These 15° intervals are the hours.

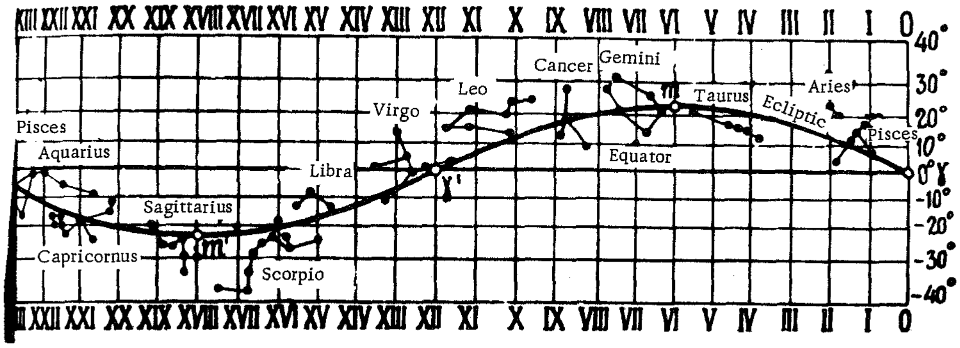


FIGURE 6. The ecliptic, the equator, and the Signs of the Zodiac

18 Figure 6 shows the constellations of the zodiac marked on an astronomical map of the sky. The equator and the ecliptic are also shown. This map was obtained by projecting the celestial sphere, the ecliptic and the equator from the center of the Sun onto the surface of a cylinder (Figure 7) enclosing the celestial sphere and the tangent to it along the equator. The cylinder is then unrolled and a rectangular map is obtained (Figure 6). This procedure is known as Mercator projection.

(17)

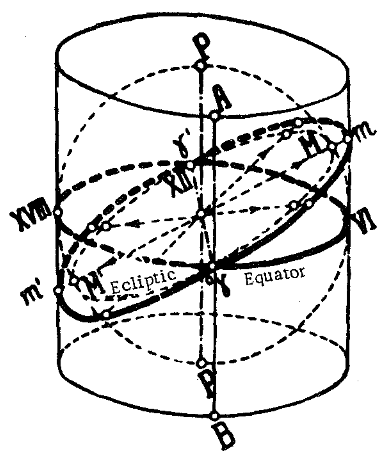


FIGURE 7. Mercator projection of the sky

A different projection technique (Figure 8) projects the celestial sphere either from the South Pole (P') onto a plane tangent to the celestial sphere at the North Pole, or vice versa, from the North Pole onto a plane tangent at the South Pole. The constellations, the ecliptic, and the equator on a sky map obtained by this method are shown in Figure 9. This projection is known as gram-stereographic.

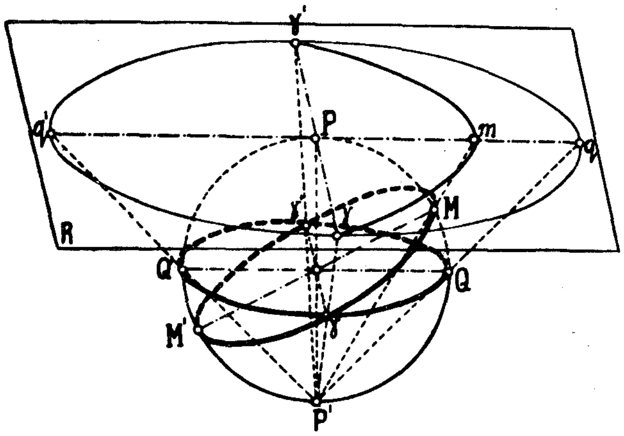


FIGURE 8. Gram-stereographic projection of the sky

CELESTIAL COORDINATES

In order to determine the position of the Sun, Moon, Earth, planets, stars and other celestial bodies in space, their orientation should be defined relative to certain planes and points, which retain fixed positions. The position of a celestial body relative to these fixed planes is determined by arcs of certain circles and is measured in degrees. These arcs are known as the celestial coordinates.

We will describe 3 systems of celestial coordinates commonly used in astronomy (Figure 10):

(20) **The horizontal system.** The principal direction coincides with the vertical line passing through the center of the Sun and meeting the sky at two points, the zenity Z and the nadir Z'. The plane passing through the center of the Sun C perpendicular to the line ZZ' is known as *the plane of the horizon*, or *the horizontal plane*; its intersection with the celestial sphere defines the horizon. Any plane crossing the line ZZ' is perpendicular to the plane of the horizon, and is appropriately known as *the vertical plane of the vertical.*

(19)

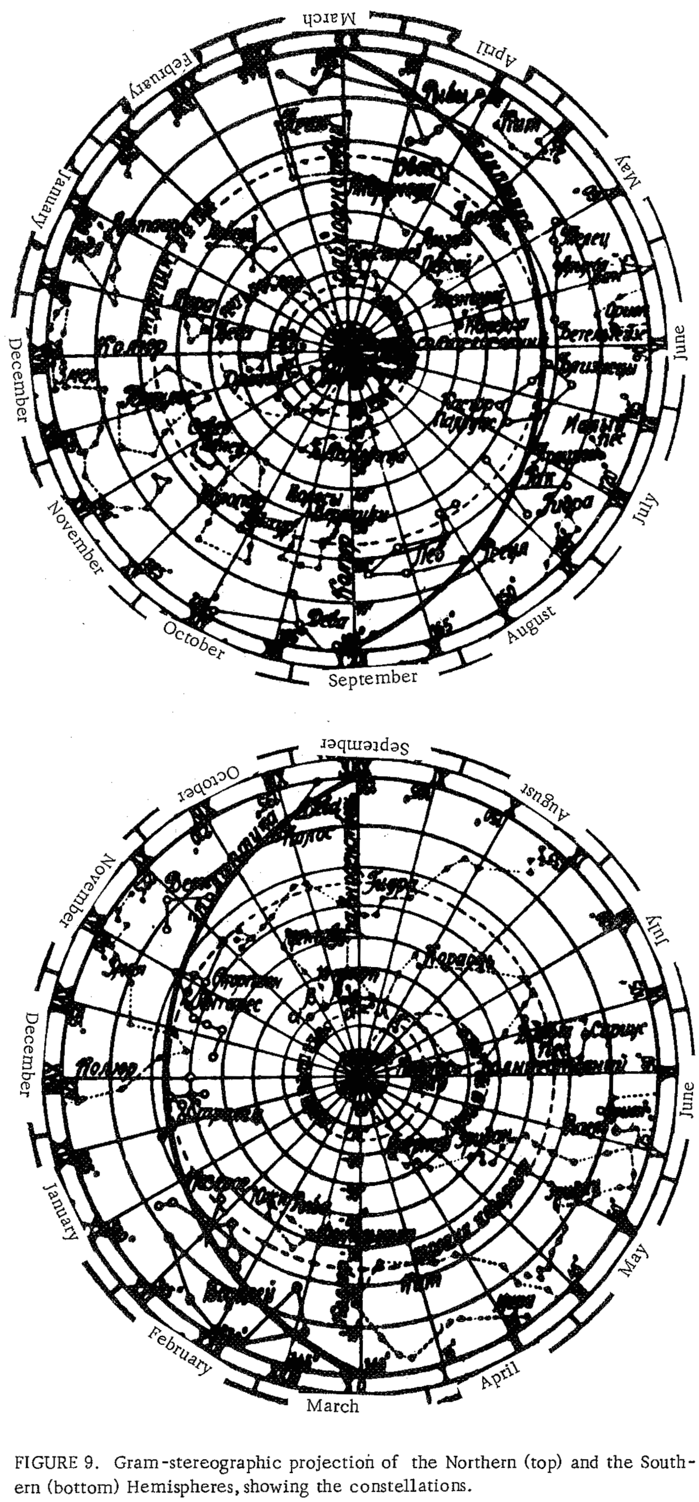


FIGURE 9. Gram-stereographic projection of the Northern (top) and the Southern (bottom) Hemispheres, showing the constellations.

The vertical plane passing through the axis of the celestial sphere PP' and the line ZZ' is adopted as the principal vertical. It is called the plane of the local meridian or briefly the local meridian. This plane crosses the horizon at 2 points: South (S) and North (N). The line NS is known as the noon line. The points of West (W) and East (O) are located on the horizon at right angles to the noon line. The position of a celestial body E in this system is defined by the following coordinates: 1) the azimuth A, i.e., the arc SWB reckoned from the south point S in the westward direction (from 0—360°) and 2) the altitude H, i.e., the arc BE from the horizon to the object, reckoning along the vertical (from 0—90°).
21 The altitude can be replaced by the zenith distance $z = ZE$, which is reckoned along the vertical from the zenith Z. These two coordinates vary continuously with the rotation of the Earth about its axis.

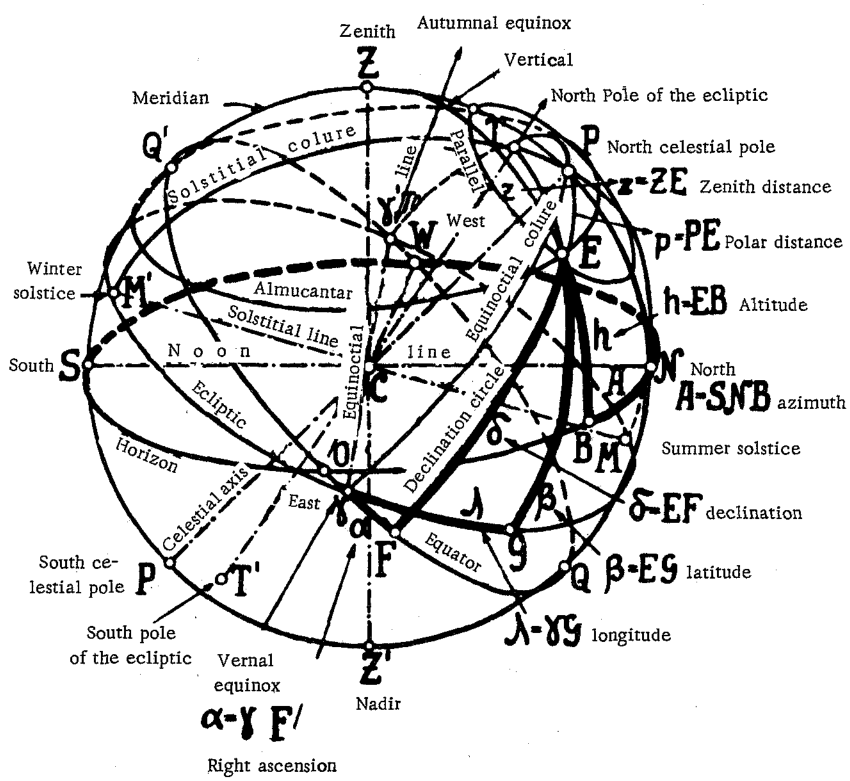


FIGURE 10. Celestial coordinates

Circles on the celestial sphere parallel to the horizon are known as almucantars (e.g., the circle through the celestial object E).

The equatorial system. The main elements of this system are the equator and the circle passing through the axis of the celestial sphere and the line of equinoxes $\gamma\gamma'$. This circle is known as the equinoctial colure. To fix the position of a celestial body E, a circle is drawn through it and through the axis of the celestial sphere. The arc FE of this circle from the equator to the celestial object is known as the declination. The arc p = PE complementing the declination to 90° is known as the polar distance.

The second coordinate in the equatorial system is the arc $\gamma F = \alpha$ from the point γ to the celestial meridian, reckoned from west to east through south (from 0 — 360°). This arc is known as the right ascension of the object. The right ascension is occasionally replaced by the hour angle, which is reckoned along the equator from the local meridian, i.e., the arc Q'WF from the point Q' to the celestial meridian in the westward direction. Note that the circles on the celestial sphere which are parallel to the equator are known as the parallels.

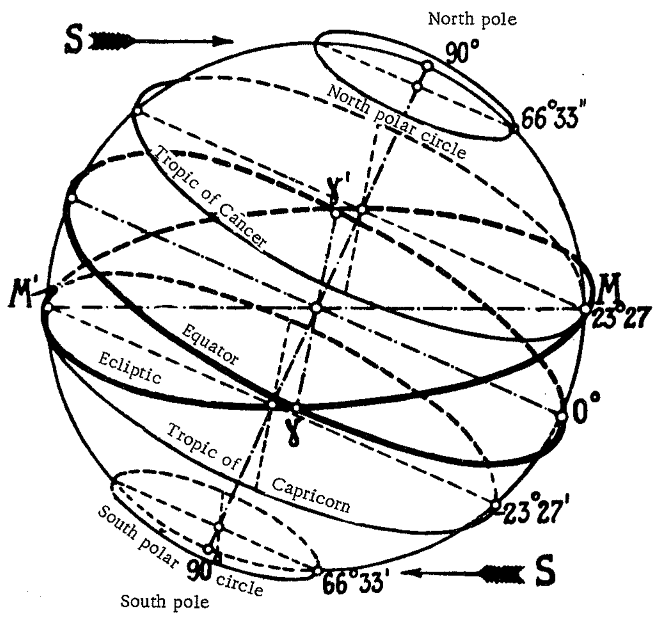


FIGURE 11. Various circles on the celestial sphere

The ecliptic system. The coordinates in this system are the latitude β = EG reckoned from the ecliptic to the object along the circle passing
22 through the object and the poles of the ecliptic and the longitude $\lambda = \gamma G$ reckoned along the ecliptic from the point y to the latitude circle. Note that the circle passing through the axis of the celestial sphere and the line of solstices is known as the solstitial colure.

The circles on the celestial sphere parallel to the equator and tangent to the ecliptic (Figure 11) are known as the Tropic of Cancer and the Tropic of Capricorn. The circles parallel to the equator at a distance of 23°27' from the poles are known as polar circles.

The parallax (p_1, Figure 12) of the Sun, the Moon, and the planets is the angle subtended at their center by the Earth's radius (r_1) drawn from the Earth's center to the point a from which the celestial body is being observed.

The horizontal equatorial parallax of these celestial bodies is the analogous angle p when the radius r is perpendicular to am. For the Moon, p = 57', for the Sun p = 8.8". Figure 12 (bottom) shows the position of the Moon and the Earth to scale and their relative dimensions. Half the angle subtended by the Earth from the Moon is 57'.

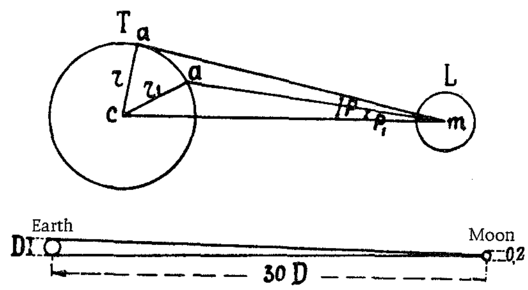


FIGURE 12. Parallax

When measuring the distances of stars from the Earth, the Earth's radius is assumed to be negligibly small compared to interstellar distances, and the basis (r) is therefore identified with the radius of the Earth's orbit perpendicular to the line joining the Sun and the star.

In other words, the parallax of a star is the angle subtended from the star by this particular radius of the Earth's orbit. For example, the parallax of the star α - Centauri is 0.75".

TIME

Sidereal time is the time defined by the rotation of the Earth relative to the stars. The sidereal day is the time interval between two successive transits of a certain star through the local meridian in the course of its eastward motion. All sidereal days are equal.

23 **Solar or true time** is determined by the rotation of the Earth relative to the Sun. The solar day is the time interval between two successive transits of the local meridian through the center of the Sun. On the average, the solar day is almost 4 min longer than the sidereal day. The length of the solar day is variable. It depends on various factors, which include the nonuniform motion of the Earth along its elliptical orbit and the inclination of the orbit to the equator. In general, on 22 December the solar day is longer than average, and on 17 September it is shorter than average. The difference between the longest and the shortest solar day over an entire year is about 51 sec of mean solar time, and the mean solar day is equal to 24 hr 3 min 56.555 sec of sidereal time.

Local time is the mean solar time at a given locality.

Standard (zone) time for a given zone of the Earth is the time of the prime meridian of the zone; the two edges of the zone have clocks which differ by no more than half an hour from the clock of the prime meridian.

Civil day begins at midnight.

Astronomical day begins at noon.

The sidereal years is the time for the Earth to complete one revolution around the Sun, and the direction from the Sun is determined by the position of the fixed stars. The sidereal year is equal to 365 days 6 hr 9 min 9.54 sec of mean solar time.

The anomalistic year is the time for the Earth to move between 2 successive perihelia of its orbit. It is slightly longer than the sidereal year, being equal to 365 days 5 hr 13 min 53.01 sec of mean solar time.

The tropical year is the time between two successive passages of the Earth through the equinoctial line. This year is shorter than the sidereal year and is equal to 365 days 5 hr 48 min and 45.92 sec of mean solar time.

International time. Almost all the countries of the world measure time in the same units (hours, minutes and seconds). The Earth's surface is partitioned by meridians into 24 hour zones, each with constant standard time and a time difference of one hour between adjacent zones. Starting with the zone which includes the Greenwich meridian, the standard zones are marked from west to east by numerals from 0 to XXIII.

The entire territory of the Soviet Union extends from the boundary between zones I and II to the boundary between zones XII and XIII. The exact time zone boundaries for the USSR will be found in the Official Time Table of Railway, Steamer, and Other Passenger Transport, Izdatel'stvo NKPS (Transpechat').

The following 3 different standard times are used by the railways in Europe:

a) Central European Time (CET), corresponding to the time of the 15th meridian east of Greenwich, i.e., the time of zone I: Denmark, Germany,
24 Italy, Yugoslavia, Lithuania, Norway, Austria, Poland, Sweden, Switzerland, Czechoslovakia, and Hungary.

b) West European Time (WET), identified with Greenwich Mean Time (i.e., the time of zone 0 or zone XXIV, running one hour behind CET): Belgium, France, Great Britain, Portugal, Spain, and the West-German occupied territories.

c) East European Time (EET), corresponding to the time of the 30th meridian east of Greenwich, i.e., the time of zone II (clock running one hour ahead of CET): Bulgaria, Rumania, Turkey, Egypt, Finland, Estonia, Latvia, USSR.

The official Railway Timetable gives the standard time of zone II. To convert to local time, one hour should be added in zone III, 2 hr in zone IV, 3 hr in zone V, etc.

River and sea transport follow the rules listed in the Timetable.

MOTION OF THE EARTH

The Earth traces a highly complex path in space, and its motion is governed by numerous factors, including the attraction of the Sun and other planets. Let us consider its motion in general outline.

First motion. Axial rotation of the Earth: we considered this component of motion in the previous section.

Second motion. Orbital motion of the Earth around the Sun in its elliptical orbit.

Third motion. "Precession of the equinoxes." The Earth's axis slowly describes a cone in space, the axis of the cone passing through the north pole of the ecliptic (Figure 13). The opening angle of this cone is 47°. Figure 9 shows the dashed circles traced by the poles. The period of this precession is 25,765 years.

Fourth motion (Figure 14). Lunar perturbations. Because of its monthly motion around the Earth, the Moon somewhat displaces the Earth in space and both planets revolve around a common center of gravity as a single object. Since the mass of the Moon is 1/80th of the Earth's mass, the center of gravity is distant from the center of the Earth 1/80th of its distance from the center of the Moon, i.e., it is located at a distance of 4,618 km from the Earth's center, and the Earth completes one circuit about this point each month.

25 During the new moon phase, when the Moon lies between the Sun and the Earth, the Earth (C_1) is slightly closer to the Sun. During the full moon phase, the Earth (C_3) is slightly farther from the Sun, during the first quarter it slightly lags (C_2) and during the third quarter it slightly precedes the mean position (C_4). Lines a, b, c, d in Figure 14 mark the points where the Earth would have been observed had there been no lunar perturbation.

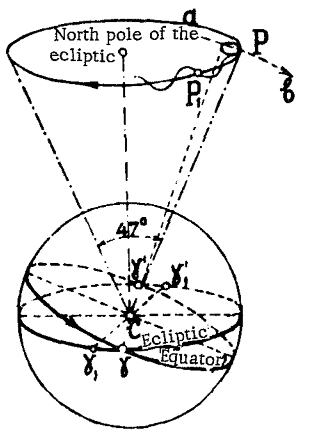


FIGURE 13. Precession of the equinoxes and nutation

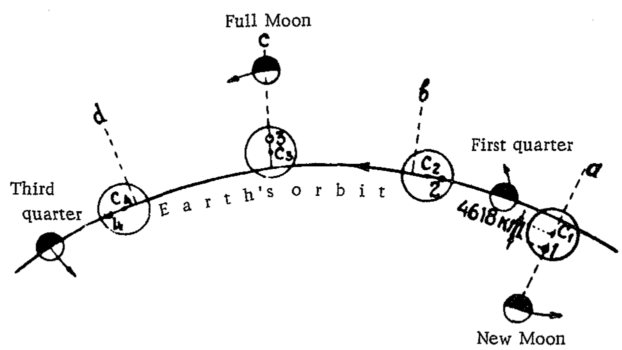


FIGURE 14. Effect of the Moon on the Earth's orbit

Fifth motion. "Nutation" (Figure 13). While the Earth's axis moves, tracing a cone with a period of 25,765 years (third motion), the Moon forces the axis to undergo slight oscillations with the result that it traces a small ellipse in the sky, 18'' long and 14'' wide. The period of this motion is 18.5 years. The third and fifth motions (precession and nutation) of pole P combine into a wavy line with 18.5 years elapsing between P and P_1.

Sixth motion. Alteration of the inclination of the ecliptic. The equator rocks slightly, relative to the ecliptic; the amplitude of this rocking motion
26 does not exceed 2°37', and the deviation does not exceed 0.5'' per year. Because of this motion, the axis of the celestial sphere alternately approaches to and recedes from the line of the ecliptic poles (ab in Figure 13), and the third, fifth, and sixth motions combine to move the pole along a path not unlike the pulsating hairspring of a watch.

Seventh motion. The elliptical shape of the Earth's orbit changes (Figure 15). The ellipse alternately grows longer and shorter, successively assuming profiles 1, 2, 3. In the year 24,000, the orbit will be almost circular (3).

Eighth motion. Rotation of the Earth's orbit in its own plane (Figure 16). The line of apsides or the major axis of the orbital ellipse rotates in the orbital plane, completing one circuit in 21,000 years. This motion is caused by the influence of the planets.

(25)

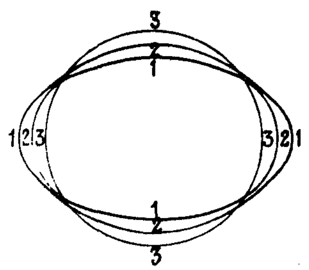


FIGURE 15. Deformation of the Earth's orbit

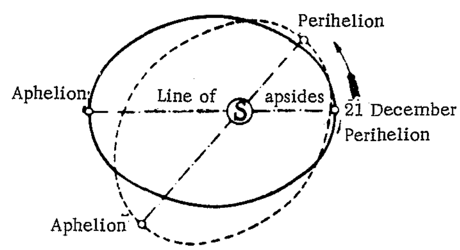


FIGURE 16. Rotation of the Earth's orbit

Ninth motion. Perturbations produced by the gravitational attraction of Jupiter cause the Earth to recede somewhat from the Sun (Figure 17). Similar perturbations are caused by other planets when near the Earth.

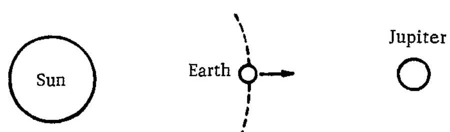


FIGURE 17. Perturbation of the Earth's motion

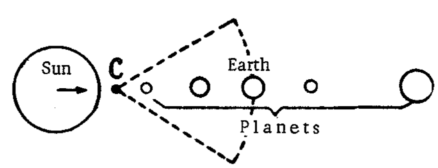


FIGURE 18. Effect of Sun's displacement on the Earth

Tenth motion (Figure 18). When all the planets lie on one side of the Sun, they displace the Sun's center in the corresponding direction. Since
27 the Earth rotates around the center of gravity of the entire system, and not the exact center of the Sun, this displacement introduces a further complicating factor in its motion.

(26)

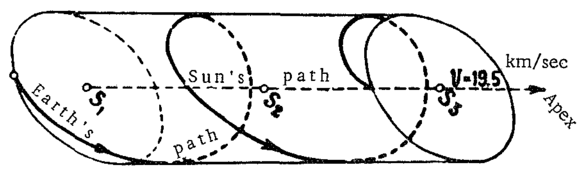


FIGURE 19. Effect of Sun's motion on the Earth's orbit

Eleventh motion. The Sun itself moves through space with a velocity of 19.5 km/sec, toward a point of the sky in the constellation of Lyra, near the star Vega. This point is known as the solar apex. The right ascension of this point is 280° and its northern declination is 35° (see Figure 10). The Earth's orbit is entrained with the Sun, so that the actual path of the Earth in space is not a closed ellipse, but rather a helix (Figure 19). The line of the apex makes an angle of 38° with the line of the ecliptic.

(26)

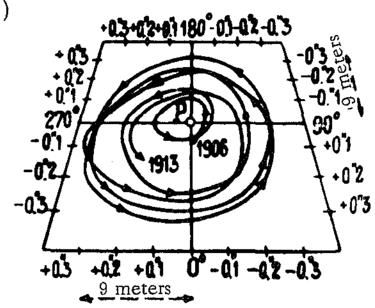


FIGURE 20. Variation of latitudes

Twelfth motion. Regardless of the position of the axis of the celestial sphere, the Earth changes its orientation relative to this axis, so that the Earth's poles steadily migrate on the surface. Figure 20 traces the migration of the North Pole between the years 1906 and 1913. This phenomenon is known as variation of latitude. The Pole does not recede more than 9 m from its mean position.

MOTION OF THE MOON

A silent maiden of eternal beauty,
Thou art immortal, irresistible,
Impassive, and unshakeable.
How fair and clear is thine regal look.

B.Sadovskii, "Polden'" ["Noon"] (Poems, p.110)

The Moon (Figures 21 and 22) is most likely the nearest station for the interplanetary rockets of the future. Our survey of the solar system will therefore begin with a description of the Moon. It is the Earth's satellite,

(28)

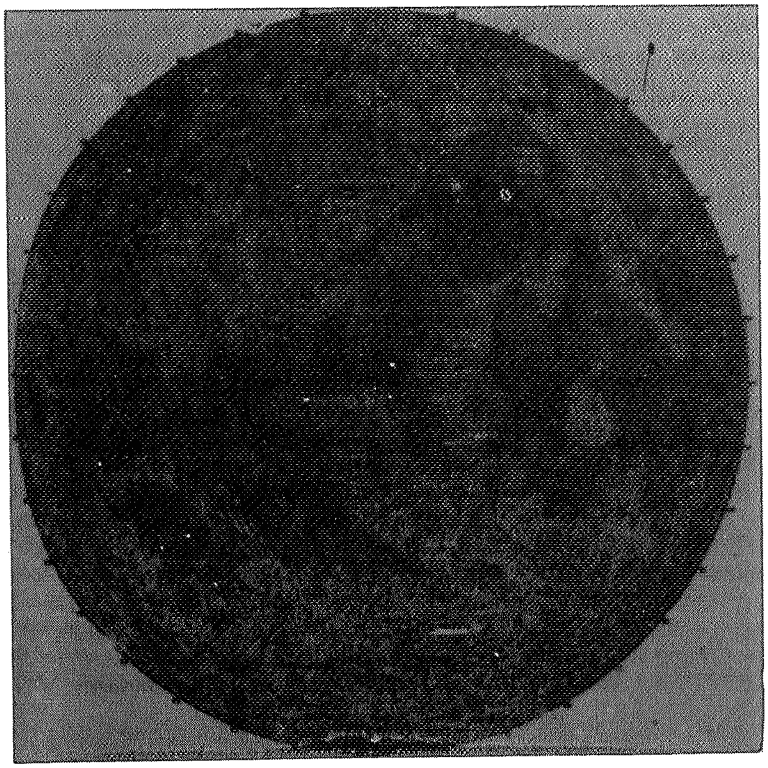


FIGURE 21. A map of the Moon

(28)

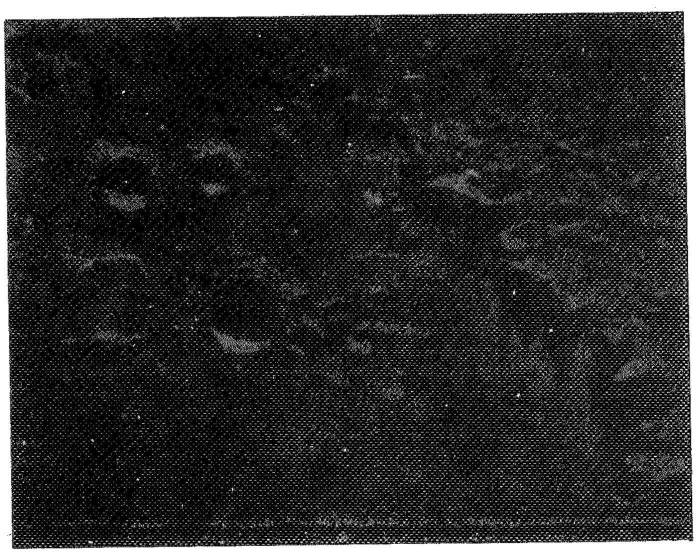


FIGURE 22. A detail of the lunar surface

distant 384,300 km from the primary planet; light covers this distance in slightly over 1 sec. Figure 23 shows to scale the relative size of the Moon and the Earth, velocities of their motion, and the distance between them. More exact characteristics of the Moon are given in Table 2.

The motion of the Moon around the Earth is even more complex than the motion of the Earth itself. Astronomers list 16 different irregularities of this motion.

(29)

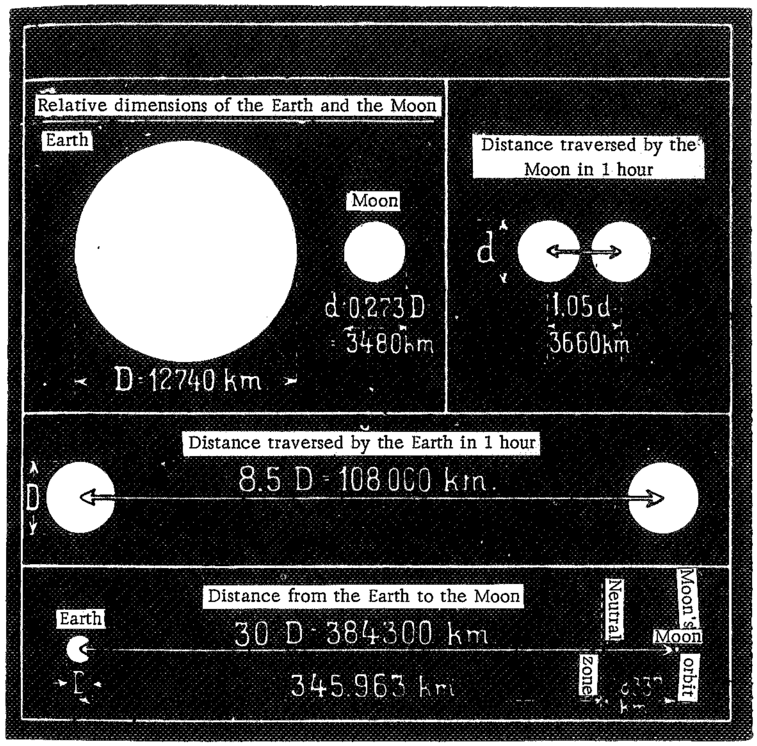


FIGURE 23. The Earth and the Moon

We will consider the main components of lunar motion.

First motion. Axial rotation. The period of axial rotation is one month, which is equal to one lunar day. We distinguish between 2 different lunar days: sidereal day, equal to 27.32166 mean solar days; and solar day, equal to 29.530588 mean solar days. A lunar month is generally reckoned on the sidereal scale.

Second motion. Motion in an elliptical orbit around the Earth. Figure 24 shows the first and the second motion of the Moon. Since both motions have the same period, the Moon constantly turns the same side to the Earth (a). The same figure shows the aspects (phases) of the Moon as

30 seen from the Earth during different days of the month.

(29)

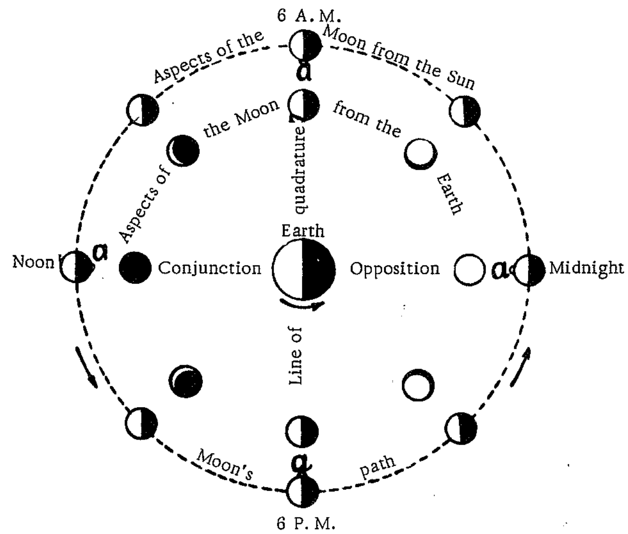


FIGURE 24. The first and second motions of the Moon

Third motion. The elliptical orbit of the Moon (L) turns around the Earth (T) (Figure 25). The period of this rotation is 3,232 days.

Fourth motion. The lunar orbit does not lie in the plane of the Earth's orbit: the 2 orbits make an angle of some 5°. The intersection line of the 2 orbits is known as the line of nodes (KK). The lunar orbit turns around the axis II, describing a complete circuit in 6,793 days, or $18\frac{2}{3}$ years. The line of nodes (KK) thus completes one revolution in this period.

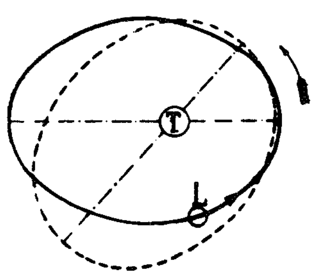


FIGURE 25. The third motion of the Moon

Fifth motion. The inclination of the lunar orbit to the Earth's orbit varies from 5°0'1" to 5°17'35". The period of this variation is 173 days (Figure 26). Figure 27 shows the combined effect of 2 lunar irregularities: 1) the rotation of the plane of the lunar orbit around the Earth, the extreme orientations of the lunar orbital plane in the plane of the Earth's orbit making an angle of some 5°. As a result of this motion, the line of nodes, i.e., the line of intersection of the orbits of the Earth and the Moon, successively occupies positions Ω_1, Ω_2, etc.; 2) the rotation of the lunar orbit in its plane (9 years to complete one turn), i.e., the so-called rotation of the lunar perigee. These 2 motions combine to drive the Moon inside a ring which is shown in plan and in section in Figure 27.

31 **Sixth motion.** Lunar libration. Since the Moon moves in an elliptical orbit around the Earth, the part of the lunar surface viewed from the Earth changes slightly depending on the exact position of the Moon in its orbit. The Moon seems to rock about its mean position relative to the Earth. This

32 rocking motion is known as libration in longitude (libration from the Latin word "libra", scales). The largest amount of libration is about 8°. There is also libration in latitude (about 7°), because the plane of the lunar orbit makes an angle of 5° to the plane of the Earth's orbit. We always see 41% of the lunar surface, and librations add another 18% to the visible face of the Moon.

(30)

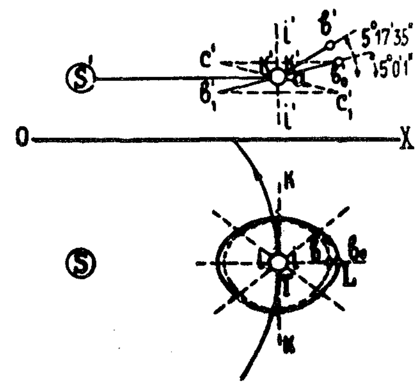


FIGURE 26. The fourth motion of the Moon

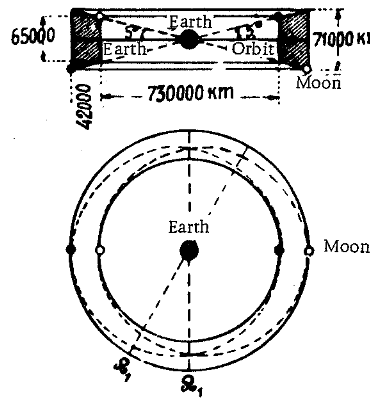


FIGURE 27. The motion of the lunar perigee

The orbit of the Moon about the Sun is shown in Figure 28. We see from the drawing that this orbit is always concave relative to the Sun. Black circles mark the position of the Moon in its four monthly phases, and large circles identify the lunar aspects as they are seen from the Earth.

(31)

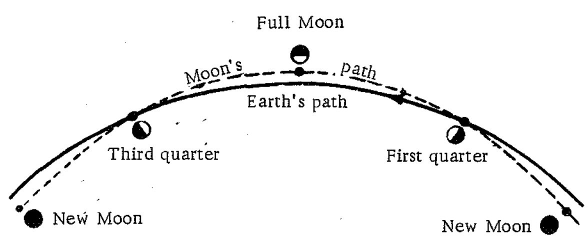


FIGURE 28. Part of the lunar orbit

Figure 29 shows in orthogonal projection the orbits of the Earth and the Moon and some of the main elements and main velocities are indicated. The velocity figures include 1) the velocity of the Earth in its orbit, 2) the velocity of a point on the Earth's equator, 3) the velocity of the Moon in its orbit.

(31)

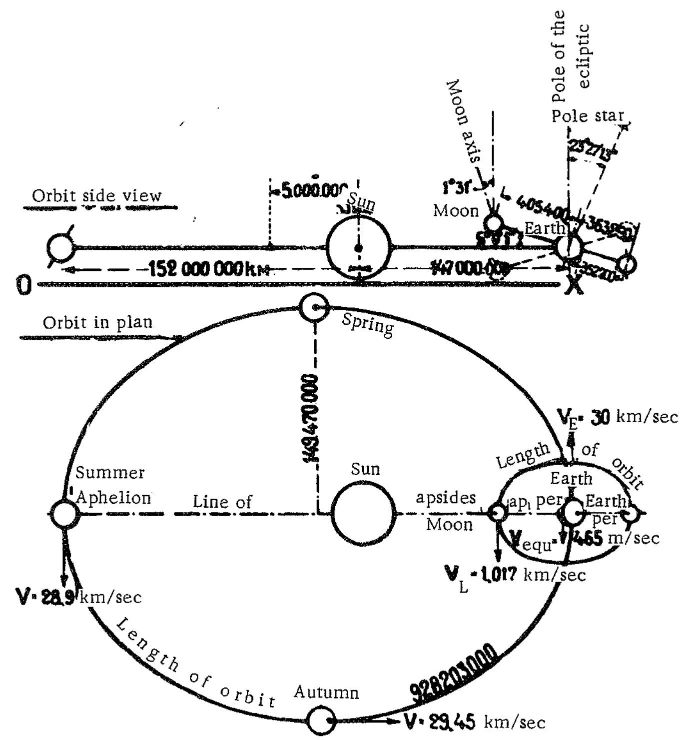


FIGURE 29. Orbits of the Earth and the Moon in orthogonal projection

PLANETS OF THE SOLAR SYSTEM

The planets are arranged in space in the following order from the Sun.

1. The Sun (Figure 30).
2. Mercury (Figure 31).
3. Venus (Figure 32).

33 4. Earth with one satellite.

5. Mars with 2 satellites (Figures 33 and 34).
6. The group of planetoids or minor planets (also known as asteroids, about 1,300 in number).
7. Jupiter with 9 satellites (Figure 35).
8. Saturn with a ring and 10 satellites (Figure 36).
9. Uranus with 4 satellites (Figure 37).
10. Neptune with one satellite.
11. Pluto.

Figure 38 shows the planets of the solar system on a scale of 34 million kilometers to one millimeter.

35 The planets situated between the Earth and the Sun are known as inferior or inner planets; all the other planets are known as superior or outer.

(32)

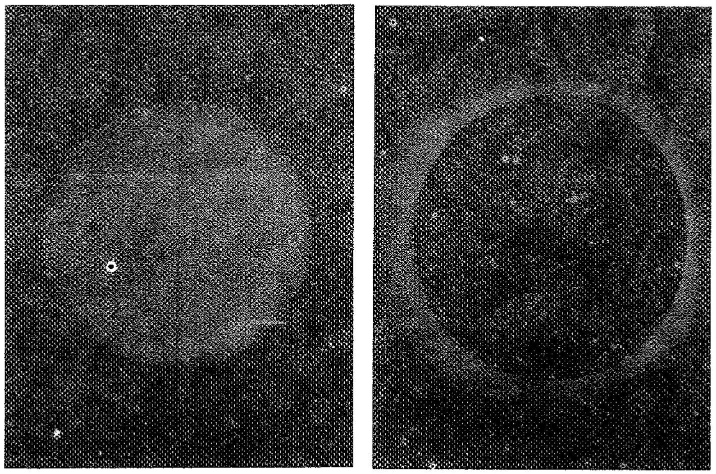


FIGURE 30. The Sun (right — total eclipse)

(33)

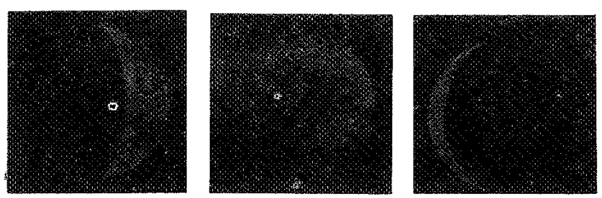


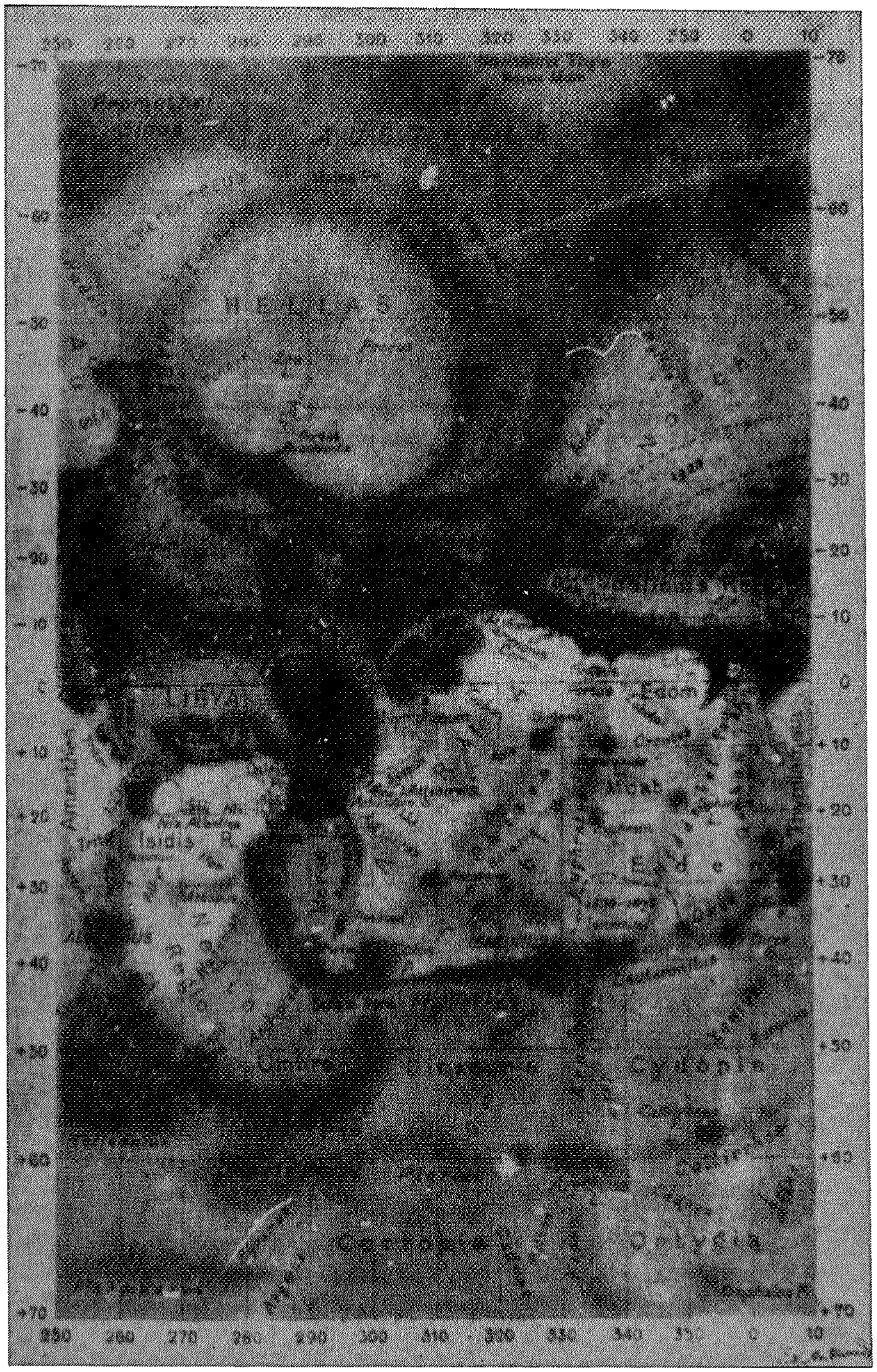
FIGURE 31. Mercury and its aspects

(33)

FIGURE 32. Venus and its aspects

FIGURE 33. Equatorial map of Mars.


Eridania
ELYSIUM
Arcadia


HELLAS
LIBYA
Edom
Moab
Isidis R.
Umbra
Cydonia
Ortygia

(34)

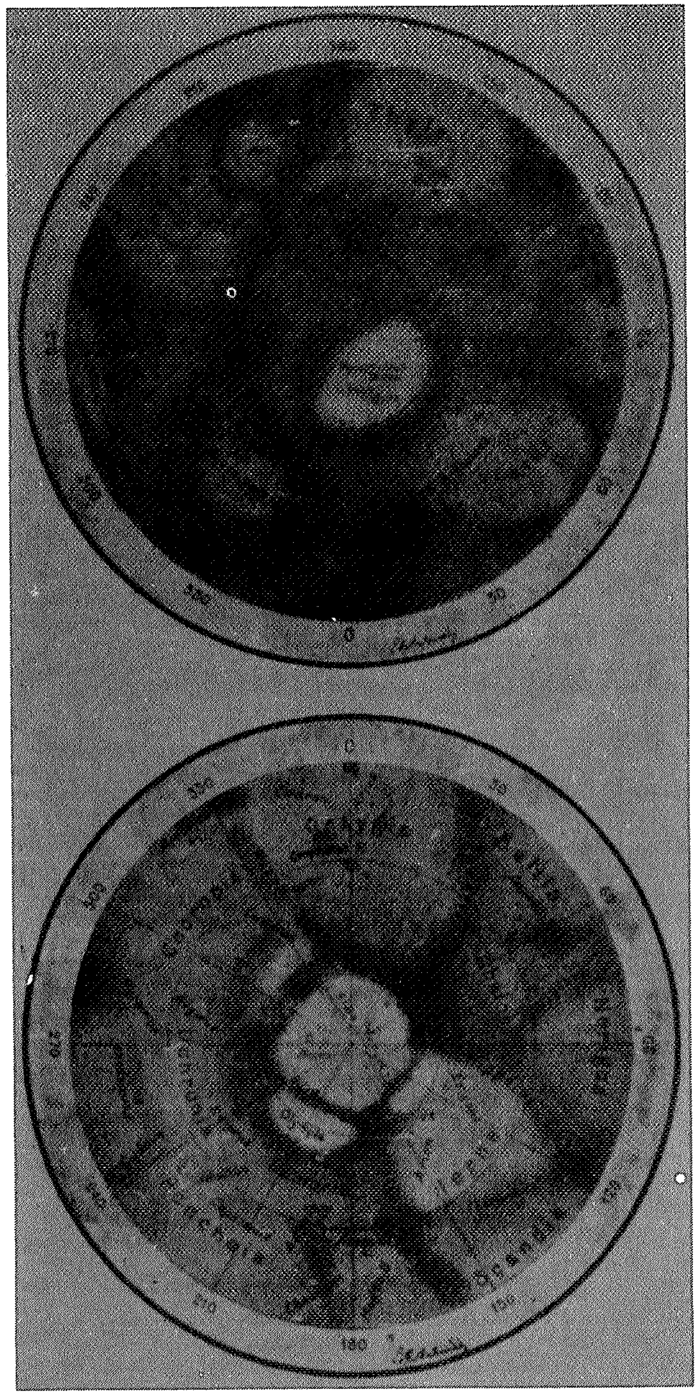


FIGURE 34. Polar maps of Mars

TABLE 2

(36)

(37)

Planet	Orbit: Radius: Million km: Mean	Perihelion	Aphelion	Eccentricity	Radii of Earth's orbit: Mean	Perihelion	Aphelion	Length in millions of km	Inclination to the Earth's orbit (to the ecliptic)
1	2	3	4	5	6	7	8	9	10
Sun	0	0	0	0	0	0	0	0	0
Mercury	57.9	45.5	69.0	0.2056149	0.387	—	—	—	7°0'10.85"
Venus	108.1	106.8	108.2	0.0068164	0.723	—	—	—	3°23'37.09"
Earth	149.5	147	152	0.0167414	1.0	—	—	928.203	0°0'0"
Moon	0.3843	0.36329	0.4054	0.0549	0.00258	—	—	2.412	5°0'1" — 5°17'35"
Mars	227.8	204.52	246.28	0.0933088	1.5237	1.3826	1.6658	—	1°51' 1.09"
Asteroids	170 — 960	—	—	0.023—0.38	2.13—3.97	1.61 — 3.31	2.39 — 4.72	—	0° — 34°41'
Jupiter	777.7	732	807	0.048335	5.203	4.952	5.454	—	1°18'31.45"
Saturn	1,425.9	1,330	1,490	0.0558923	9.5388	9.0046	10.073	—	2°29'33.07"
Uranus	2,867.4	2,700	2,968	0.046341	19.182	—	—	—	0°46'20.87"
Neptune	4,496	4,487.568	4,528.438	0.008548	30.076	30.01	30.29	27,947.674	1°46'45.27"
Pluto	6,948	—	—	0.26	43	29.9	49.6	—	17° 9'

TABLE 2 (continued)

(37)

(38)

Planet	Dimensions of Planet: Radius, mean, km	Radius, maximum, km	Radius, minimum, km	Radius, flattening	Radius, relative to Earth's radius	Circumference, km	Surface, km^2	Surface area in units of the Earth's surface	Volume, relative to Earth's volume	Volume, absolute, km^3	Density relative to the Earth	Mass relative to the Earth	Weight, relative to the Earth	Weight, absolute, tons
	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Sun	695,445	—	—	$\frac{1}{65,884}$	109.05	4,350,000	$6 \cdot 10^{12}$	11,918	1,301.107	$1,390.050 \cdot 10^{12}$	0.256	333,434		$19 \cdot 10^{26}$
Mercury	2,420	—	—	0	0.387	—	$73 \cdot 10^6$	0.144	0.055	—	1.013	0.056	—	
Venus	6,087	—	—	0	0.955	38,000	$450 \cdot 10^6$	0.913	0.873	—	0.936	0.817	—	
Earth	6,371	6,377.397	6,356.079	$\frac{1}{297}$	1	40,000	$510.065 \cdot 10^6$	1	1	$1,083.205 \cdot 10^9$	1	1	—	$58,750 \cdot 10^{17}$
Moon	1,736	—	—	$\frac{1}{183,862}$	0.273	10,940	$38 \cdot 10^6$	0.0743	0.0203	$22,150 \cdot 10^6$	0.606	0.01228	$\frac{1}{81}$	$725 \cdot 10^{17}$
Mars	3,391	—	—	$\frac{1}{190}$	0.532	21,500	$143 \cdot 10^6$	0.283	0.151	$160 \cdot 10^9$	0.714	0.108	$\frac{1}{69.5}$	$81.7 \cdot 10^{17}$
Asteroids	15–402	—	—	—	—	—	—	—	$\sum < \frac{1}{1,000}$	—	—	$\sum < \frac{1}{3}$	—	—
Jupiter	71,364	—	—	$\frac{1}{15}$	11.19	480,000	$61,963 \cdot 10^6$	119.96	1,312.1	—	0.243	318.36	—	—
Saturn	61,513	—	54,000	$\frac{1}{11.5}$	9.645	400,000	$41,216 \cdot 10^6$	87.87	821.8	—	0.116	95.22	—	—
Uranus	24,292	—	—	$\frac{1}{10}$	3.809	—	$10,407 \cdot 10^6$	14.54	55.45	—	0.263	14.58	—	—
Neptune	28,017	—	—	—	4.393	—	$9,493 \cdot 10^6$	19.34	85.07	—	0.203	17.26	—	—
Pluto	13,000	—	—	—	—	—	—	—	—	—	—	6.5	—	—

TABLE 2 (continued)

(38)

(39)

Planet	Axial rotation period in si-dereal Earth days	Orbital revo-lution about the Sun in sidereal days	Angle between axis of rotation and orbit	Velocity: Axial rota-tion at the equator, m/sec	Velocity: Mean orbital, m/sec	Force of gravity; wt of 1 kg on planet surface	Distance tra-versed by a fal-ling object in 1st sec, m	Velocity during 1st sec of fall from planet to the Sun, m/sec	Surface tem-perature, °C (on sunlit surface)	Density rela-tive to water
	26	27	28	29	30	31	32	33	34	35
Sun	25d 4hr 48min		82°45'	—	19.5–21	28.04	134.62	134.62		1.42
Mercury	87.969	87d 23hr 15min 46sec	20°	—	47	0.386	2.55	0.0196	+ 187	5.63
Venus	23hr 21min 22 sec	224d 16hr 49min 8sec	35°	—	35	0.897	4.21	0.0056	+ 65	5.19
Earth	23hr 56.4min	365.2564 d	66° 32' 47"	465	29.45	1	4.90	0.0029	+ 17	5.56
Moon	27d 7hr 43min 12sec	—	88° 29'	—	1.017	0.166	0.808	0.0029	+ 17	—
Mars	24hr 37min 23sec	686.98 d	66° 1'	—	24	0.381	1.847	0.0013	−36	3.99
Asteroids	—	1,138–2,868 d	—	—	15–20	—	—	—	—	—
Jupiter	9hr 56min	4,332,587 d	86° 56'	12,450	13	2.542	12.47	0.0001	−146	1.35
Saturn	10hr 14min 28.8sec	10, 759.22 d	63° 18'	10, 300	10	1.024	5.32	0.000032	−178	0.69
Uranus	10hr 50min	30,685.9 d	−7° 51'	—	7	1.005	4.30	0.000008	−207	1.37
Neptune	10hr	60,186.64 d	−32°	—	5.37	0.894	4.80	0.000003	−221	1.33
Pluto	—	252 yr	—	—	—	—	—	—	—	—

(35)

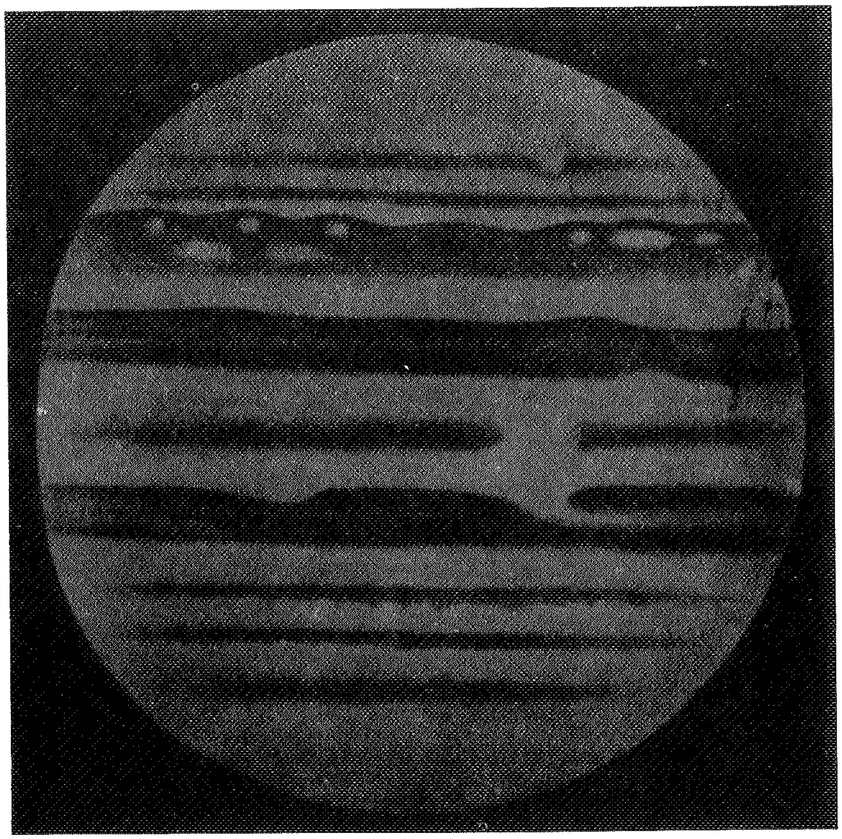


FIGURE 35. Jupiter

(40)

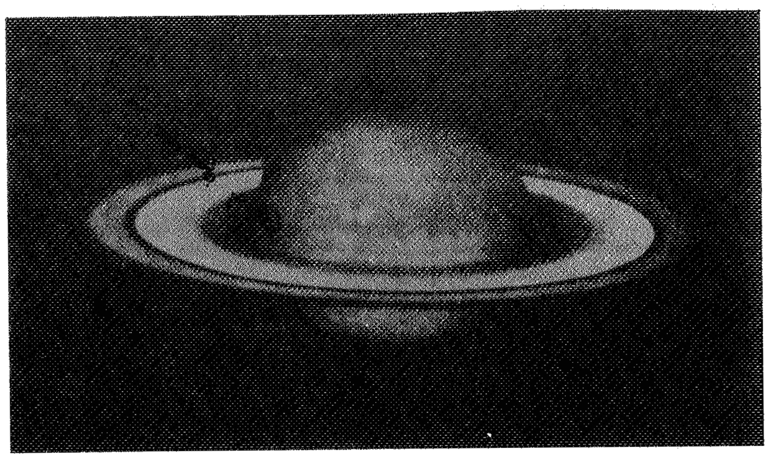


FIGURE 36. Saturn

(40)

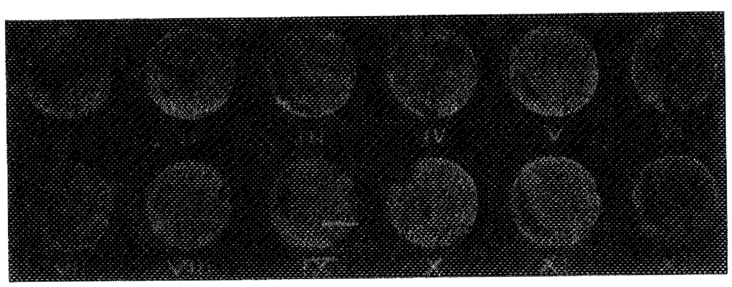


FIGURE 37. Uranus

(41)

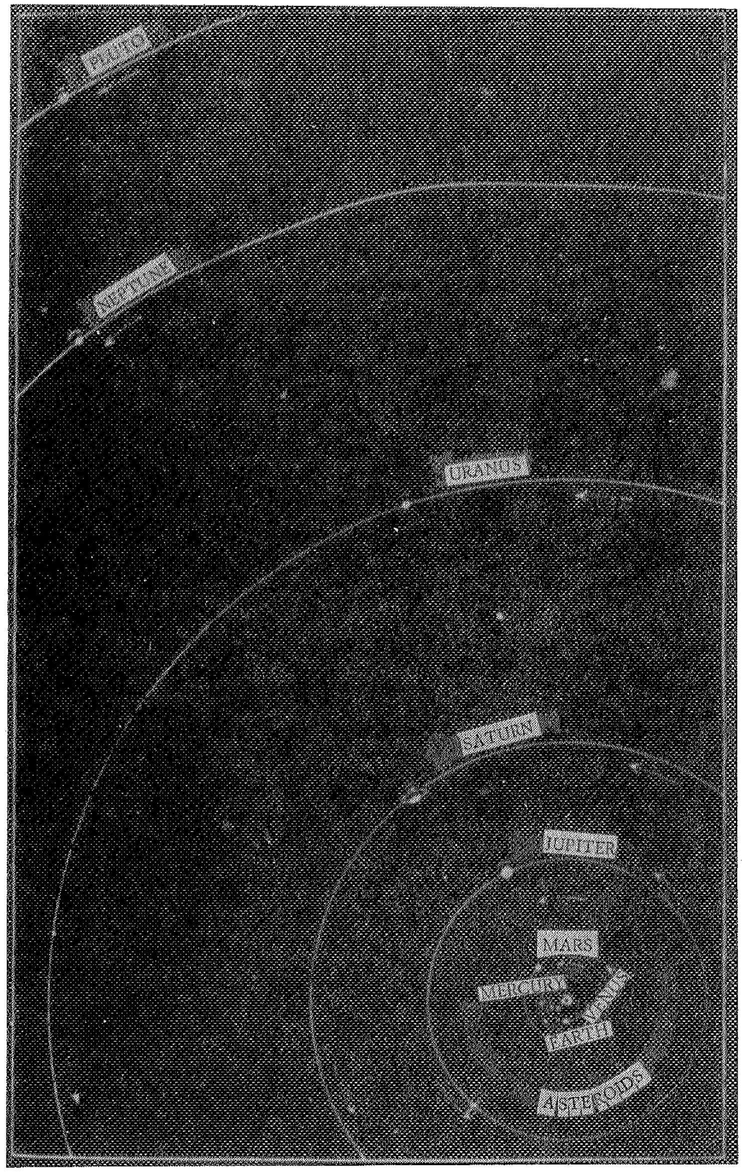


FIGURE 38. Orbits of the planets of the solar system (scale: 34 million km to 1 mm)

Figures 39 – 40 show the symbols often used for identifying the major planets. The symbol of Mercury is the stylized picture of the staff traditionally held by the Roman god Mercury. The symbol of Venus is a hand mirror. The symbol of Mars is a spear partly covered by a shield. The symbol of Jupiter is the letter Z, the first letter of the Greek name of this god, Zeus. The symbol of Saturn is the scythe of time. The symbol of Uranus is H, the first letter in the name of Herschel, the discoverer of this planet. The symbol of Neptune is the trident of the Roman sea god. Pluto is designated by 2 intertwined letters P and L, for P. Lowell, who discovered the planet, and also for Pluto.

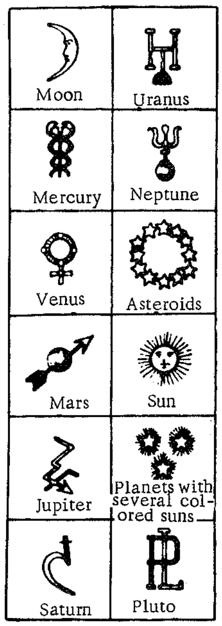


FIGURE 39. Symbols of the planets

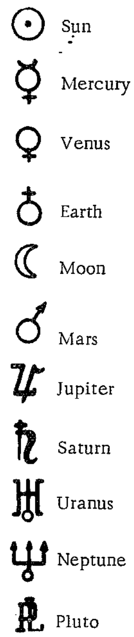


FIGURE 40. Symbols of the planets

40 Table 2 lists the principal characteristics of the orbits, the dimensions of the planets, and the elements of motion of the major planets. Figure 41 shows the relative dimensions of the Sun and the planets, and Figure 42 gives the dimensions of the Moon, Mercury, Mars, and Venus compared to Earth. Figure 41 compares our Sun with the star Canopus in the Southern Celestial Hemisphere (see Figure 9). The diameter of Antares is 487 times the diameter of the Sun, and its volume is $113 \cdot 10^6$ times the volume of the Sun and $37 \cdot 10^9$ times the volume of the Earth. The diameter of Betelgeuse is equal to 300 solar diameters (210 million km).

Figure 43 shows the relative size of the solar disk as viewed from the different planets.

42 A better idea of the tremendous distances from the Earth to other planets and stars is provided by converting these distances to the length of time for a non-stop train traveling at a speed of 50 km/hr to complete the journey. This train would have to travel:

Around the Earth	30 days	To Jupiter	740 years
To the Moon	166 "	" Saturn	1,470 "
" Venus	50 years	" Uranus	3,160 "
" Mars	76 "	" Neptune	5,055 "
" Mercury	177 "	" Pluto	6,430 "
" the Sun	300 "	" the nearest star	40 million years

(43)

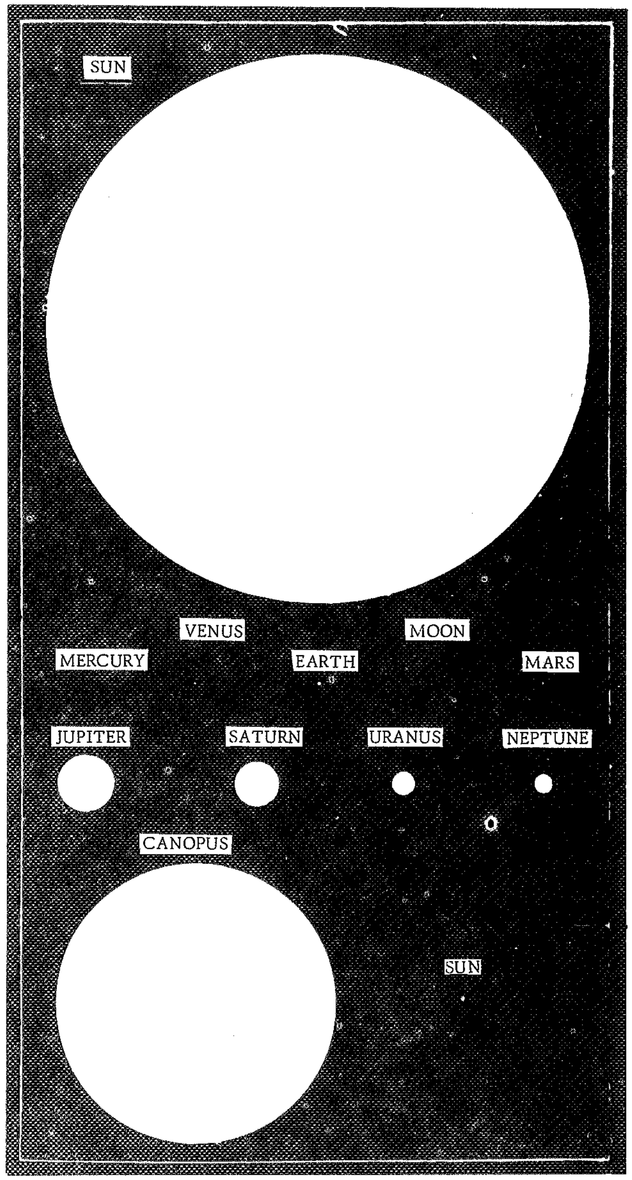


FIGURE 41. Relative dimensions of the Sun, planets, and stars

(44)

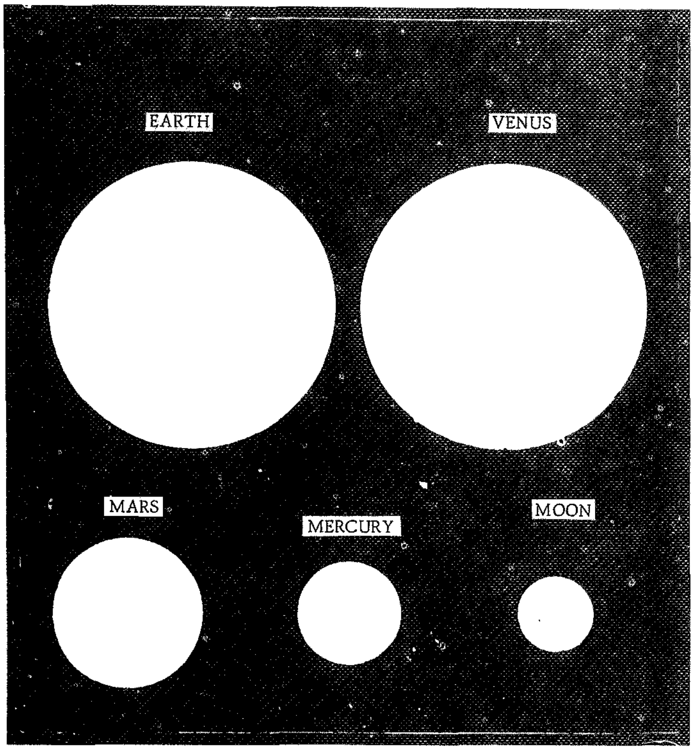


FIGURE 42. Comparative sizes of the planets

The orbital planes of the planets on the whole do not lie in the plane of the ecliptic. The following elements are needed in order to determine the exact position of these orbits (Figure 44):

1) The angle of inclination i of the orbital plane NOM of the planet to the plane of the ecliptic $X(\gamma)OY$.

2) The longitude Ω of the ascending node of the orbit, i. e., the angle between the line of intersection ON of the orbital plane with the ecliptic and the equinoctial line.

44 The ascending node N (often designated Ω) is the point of intersection of the line ON with the ecliptic.

3) The latitude Π of the perihelion Π of the planet, reckoned first along the ecliptic in the same direction as the longitude of the node, i. e., to the west, south, east, and north, to the point N, and then along the planetary orbit to the point Π. We designate the arc $N\Pi$ by ω, where ω is the nodal distance of the perihelion from the node; then

$$\Pi = \Omega + \omega.$$

The plane OZY is perpendicular to OZX and OZY. The arc $\Pi M = V$ is the true anomaly of the planet.

(45)

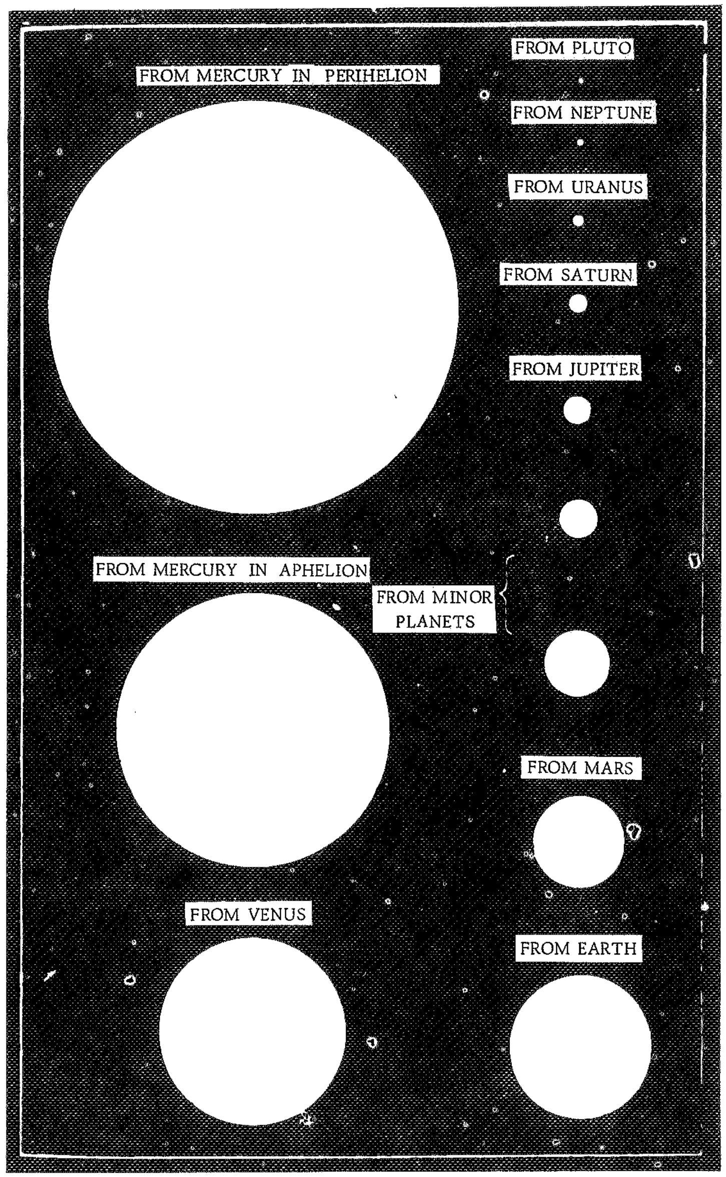


FIGURE 43. Relative dimensions of the solar disk viewed from different planets

46

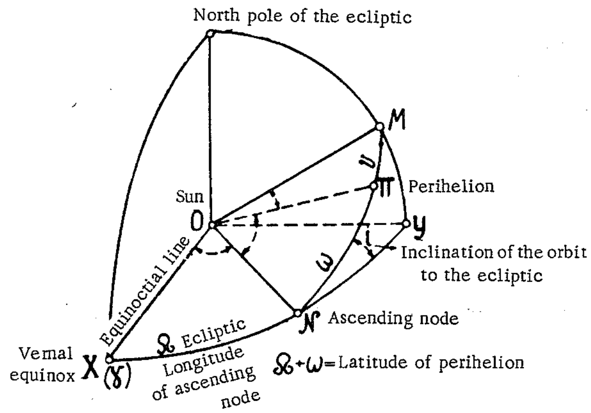


FIGURE 44. Celestial coordinates

Table 3 lists those elements which determine the position of the major planets relative to the ecliptic.

TABLE 3. Orbital elements of the major planets (1 January 1916)

Planet	Longitude		Inclination i
	ascending node Ω	perihelion Π	
Mercury	47° 20'	76° 9'	7° 0'
Venus	75° 55'	130° 23'	3° 24'
Earth	—	101° 30'	0.00
Mars	48° 55'	334° 31	1° 51'
Jupiter	99° 36'	12° 58'	1° 18'
Saturn	112° 55'	91° 24'	2° 30'
Uranus	73° 34'	169° 18'	0° 46'
Neptune	130° 51'	43° 54'	1° 47'
Pluto	109° 21' 28"	221° 40' 08"	17° 9'

48 Orbits of planets

Using the data of Tables 2 and 3, we drew the orbits of Mercury, Venus, Earth, and Mars. These orbits are shown in Figure 45; for simplicity, they were drawn as perfect circles in plan. Points 1, 2 and 3 identify the highest points of the orbits above the ecliptic.

The orbits of Mercury, Venus, and Mars were also drawn in orthogonal projection (Figures 46—48).

49 A multitude of minor planets (over 1,300 planetoids or asteroids) have their orbits between Mars and Jupiter. Some orbits emerge in part beyond

the Mars orbit, approaching the Earth's orbit, whereas others extend beyond the Jupiter orbit, closer to the Saturn orbit. The bulk of the asteroids, however, are confined between Mars and Jupiter.

(47)

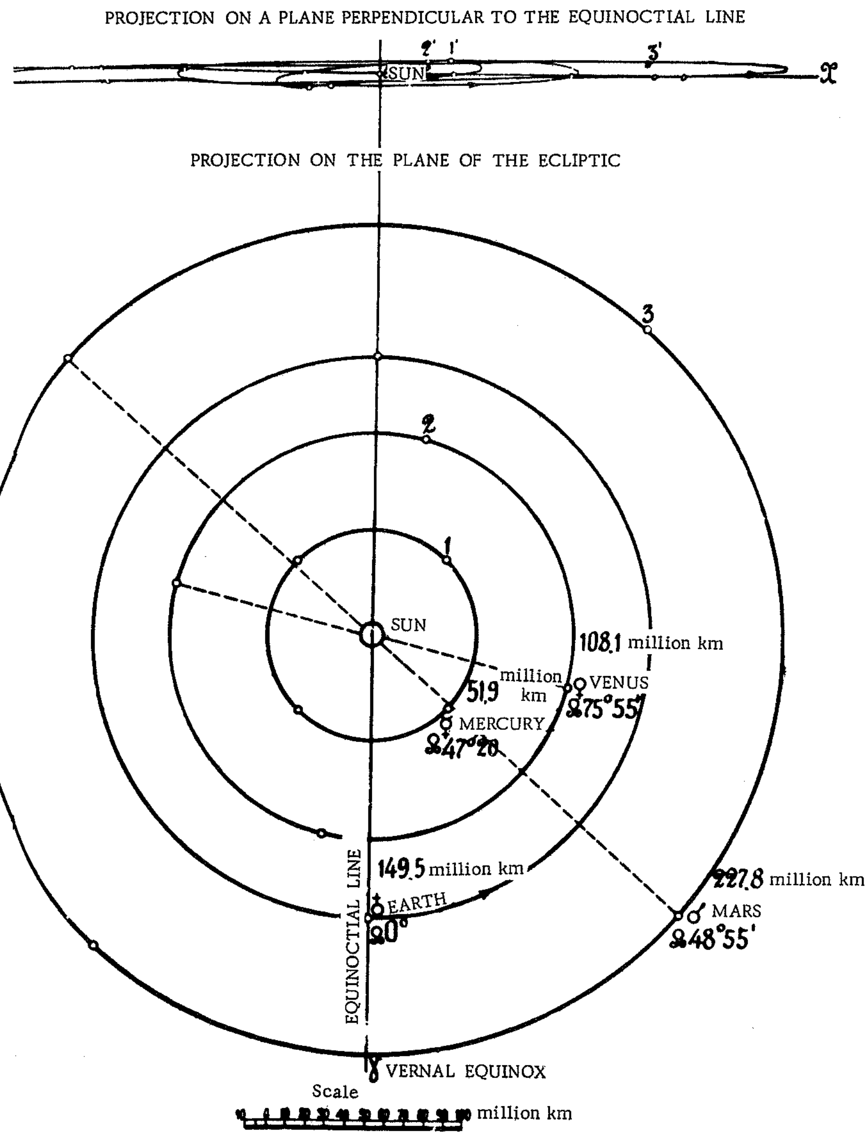
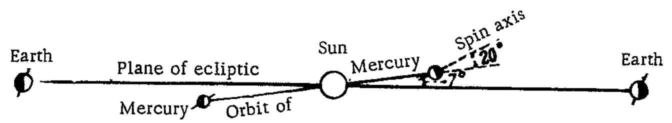


FIGURE 45. Orbits of the inferior planets in orthogonal projection

(48)



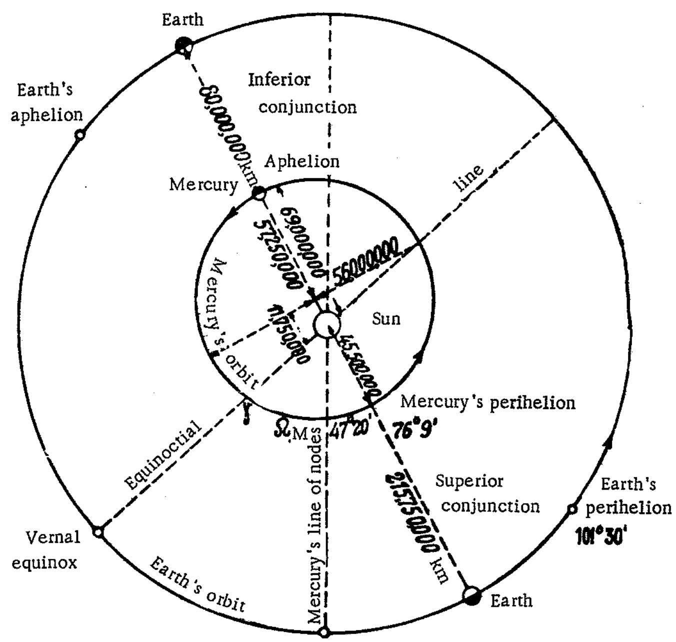
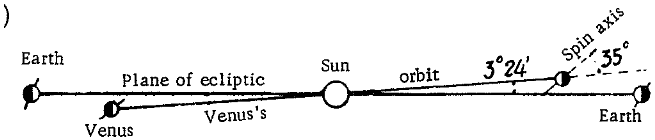


FIGURE 46. Orbit of Mercury in orthogonal projection

(49)



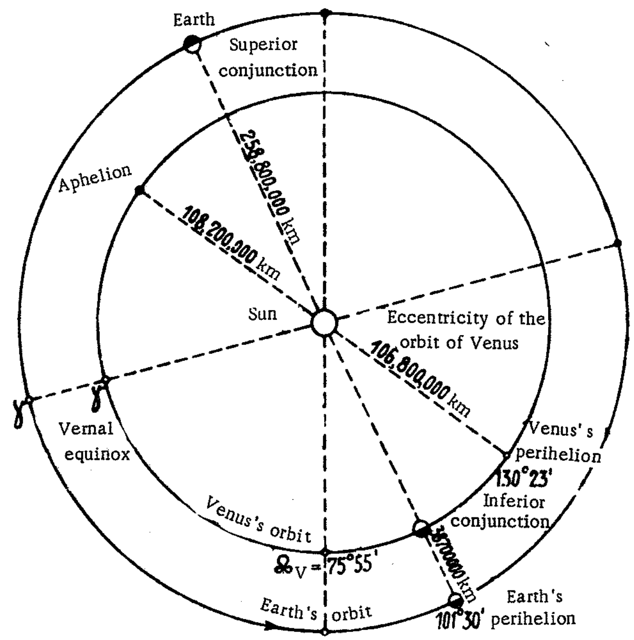


FIGURE 47. Orbit of Venus in orthogonal projection

(51)

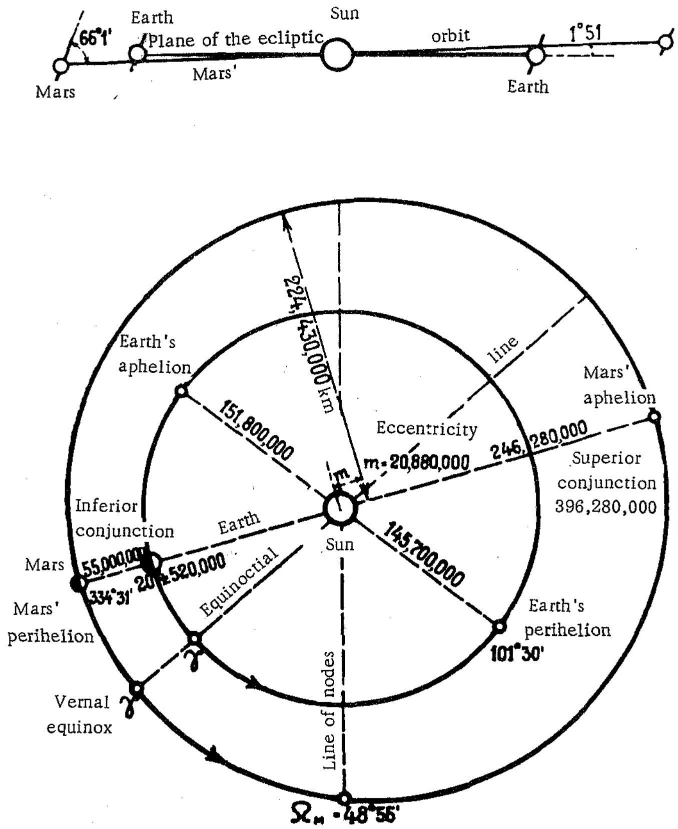


FIGURE 48. Orbit of Mars in orthogonal projection

50 The characteristics of some of the minor planets are listed in Table 4.

51 Most planetoids are listed in "Kleine Planeten," Jahrgang 1922. Oppositions - Ephemeriden (bearbeitet von dem Astronomischen Rechnen-Institut zu Berlin). Some details on their properties will be found in G. Stracke, "Die kleine Planeten," Springer, Berlin 1925.

54 The data of Table 4 were applied to construct the orbits of some planetoids in orthogonal projection (Figure 49).

We see from Figure 49 that some planetoids pass quite close to the Earth's orbit, e.g., Eros. In projection onto the vertical plane, however, their orbits markedly deviate from the plane of the ecliptic (e.g., Hidalgo, Pallas, Achilles, etc.).

55 Figure 50 plots a distribution curve of planetoids as a function of the distance from the Sun, based on Stracke's data. The vertical axis gives the number of planetoids and the horizontal axis gives the distance from the Sun, in units of the radius of the Earth's orbit (149.5 million km) on top, and the inclination of the planetoid orbits to the ecliptic at the bottom.

(50) TABLE 4. Some minor planets (over 1,300 have been discovered)

Cat. No.	Asteroid	Distance from the Sun in radii of Earth's orbit			Eccentricity	Period, days	Longitude of ascending node Ω	Longitude of perihelion ω	Inclination to ecliptic i	Radius of asteroid, km
		mean (a)	maximum	minimum						
1	Ceres	2.77	2.98	2.56	0.076	1,681	—	150°	11°	402
2	Pallas.	2.76	3.41	2.11	0.235	1,685	173° 11	309°	34° 7	243
3	Juno	2.67	3.35	1.98	0.257	1,592	—	55°	13°	95
4	Vesta	2.36	2.57	2.15	0.089	1,326	104° 3	147° 2	7° 1	196
5	Astrea	2.58	3.06	2.10	0.186	1,512	—	135	5	—
6	Hebe	2.42	2.92	1.93	0.203	1,379	—	15	15	72
7	Iris	2.39	2.94	1.83	0.231	1,346	—	41	5	70
8	Flora	2.20	2.55	1.86	0.156	1,193	—	33	6	—
9	Metis	2.39	2.68	2.09	0.123	1,347	—	71	6	60
10	Hygeia	3.14	3.49	2.80	0.109	2,036	—	238	4	80
15	Eunomia	2.64	3.14	2.15	0.187	1,570	—	28	12	75
22	Calliopa	2.91	3.20	2.62	0.101	1,812	—	60	14	62
29	Amphitrita . . .	2.52	2.71	2.34	0.074	1,491	—	56	6	65
31	Euphrosinia . . .	3.16	3.83	2.49	0.211	2,039	31° 72	60° 1	26° 4	—
33	Polymnia	2.86	3.83	1.89	0.340	1,768	—	342	2	—
36	Atlanta	2.74	3.57	1.92	0.302	1,661	—	43	19	15
39	Laetitia.	2.77	3.08	2.46	0.111	1,686	—	2	10	72
43	Ariadne	2.20	2.57	1.83	0.167	1,195	—	278	3	—
60	Echo	2.39	2.83	1.95	0.184	1,352	—	99	4	15
66	Maya	2.65	3.09	2.21	0.165	1,572	—	48	3	15
80	Sappho	2.30	2.76	1.84	0.200	1,271	—	355	9	15
117	Lomia	2.99	3.06	2.92	0.023	1,889	—	49	15	—
132	Etra	2.60	3.59	1.61	0.380	1,534	—	152	25	—
149	Medusa	2.13	2.39	1.88	0.119	1,138	—	247	1	—
153	Hilda	3.97	4.60	3.31	0.163	2,868	—	285	8	—
175	Andromache . .	3.51	4.72	2.28	0.349	2,390	—	293	4	—
180	Harumna	2.72	3.02	2.44	0.177	1,647	—	134	0	—
265	Anne	2.42	3.05	1.79	0.261	1,376	—	226	26	—
276	Adelhade	3.12	3.32	2.92	0.065	2,013	—	121	4	—
279	Thule.	4.26	4.51	4.01	0.058	—	75° 2	214° 6	2° 3	—
326	Tamara.	2.32	2.76	1.88	0.188	—	32° 4	236° 96	23° 79	—
433	Eros.	1.46	1.76	1.16	0.205	—	303° 8	177° 83	10° 8	—
588	Achilles	5.24	6.02	4.46	0.149	—	315° 8	315° 08	10° 3	—
656	Beagle	3.15	3.57	2.73	0.133	—	186° 08	322° 03	0° 44	—
891	—	2.79	2.86	2.65	0.026	—	106° 3	293° 07	13° 54	—
898	—	2.73	3.75	1.71	0.372	—	243° 28	45° 55	10°28	—
944	Hidalgo.	5.72	9.46	1.98	0.653	—	21° 37	56° 47	43° 06	—
1019	—	2.79	2.82	2.76	0.009	—	180° 64	50° 66	4° 28	—

56 The solid curve corresponds to the top scale, and the dashed curve to the bottom scale. For example, at a distance of 3.17 Earth orbit radii from the Sun, there are 73 planetoids (point a); there are 76 planetoids with orbits inclined to the ecliptic at angles between 5.1° and 6° (point b).

Figure 51 shows schematically the density of the planetoid orbits between Mars and Jupiter. The inner dashed circle marks the inner
57 boundary of the planetoids. The outer boundary corresponds approximately to the edge of Hidalgo's orbit in Figure 49. Figure 51 on the left shows a

(52)

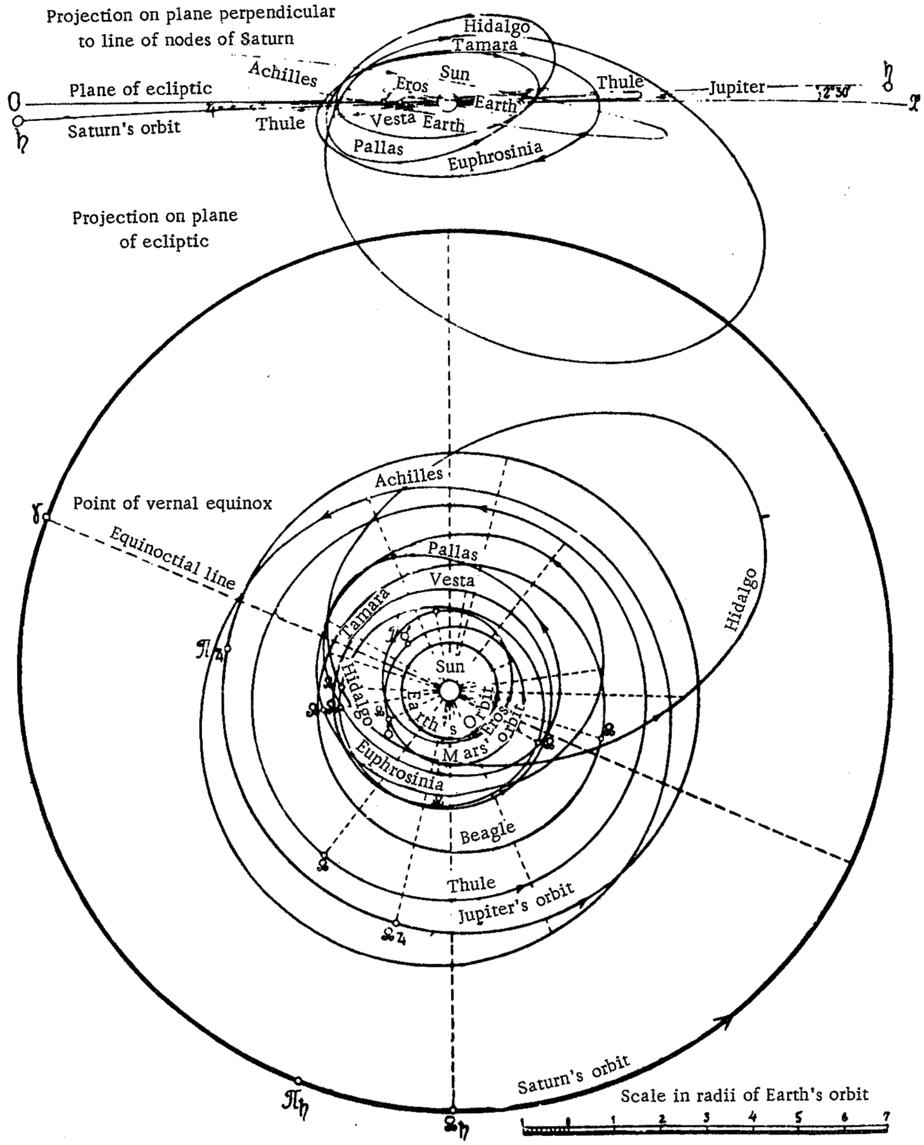


FIGURE 49. Orbits of planets and planetoids in orthogonal projection

polar diagram of the inclinations according to the number of planetoids, based on the dashed curve of Figure 50.

The orbits of Jupiter, Saturn, Uranus, and Neptune are shown in orthogonal projection in Figures 52—55, respectively. Figure 56 shows the orbits of all the superior planets in orthogonal projection.

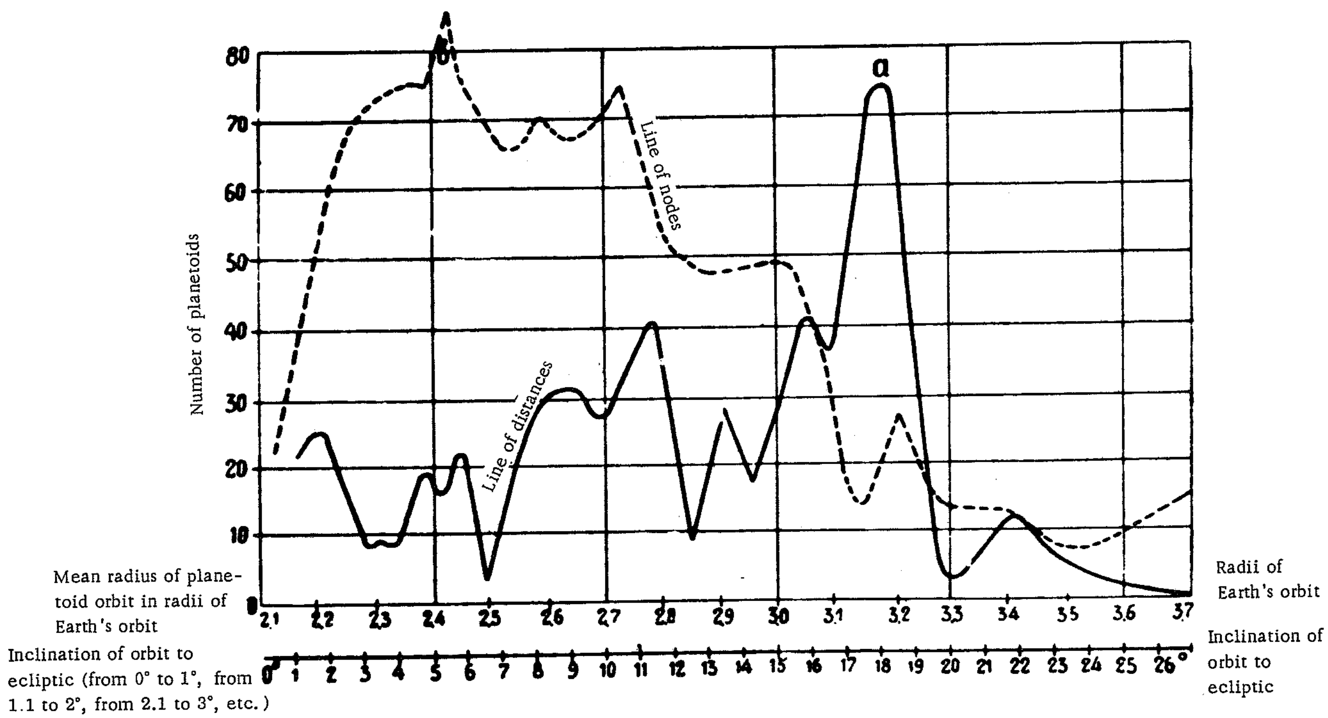


FIGURE 50. Distribution of planetoids in space and the inclinations of their orbits to the ecliptic

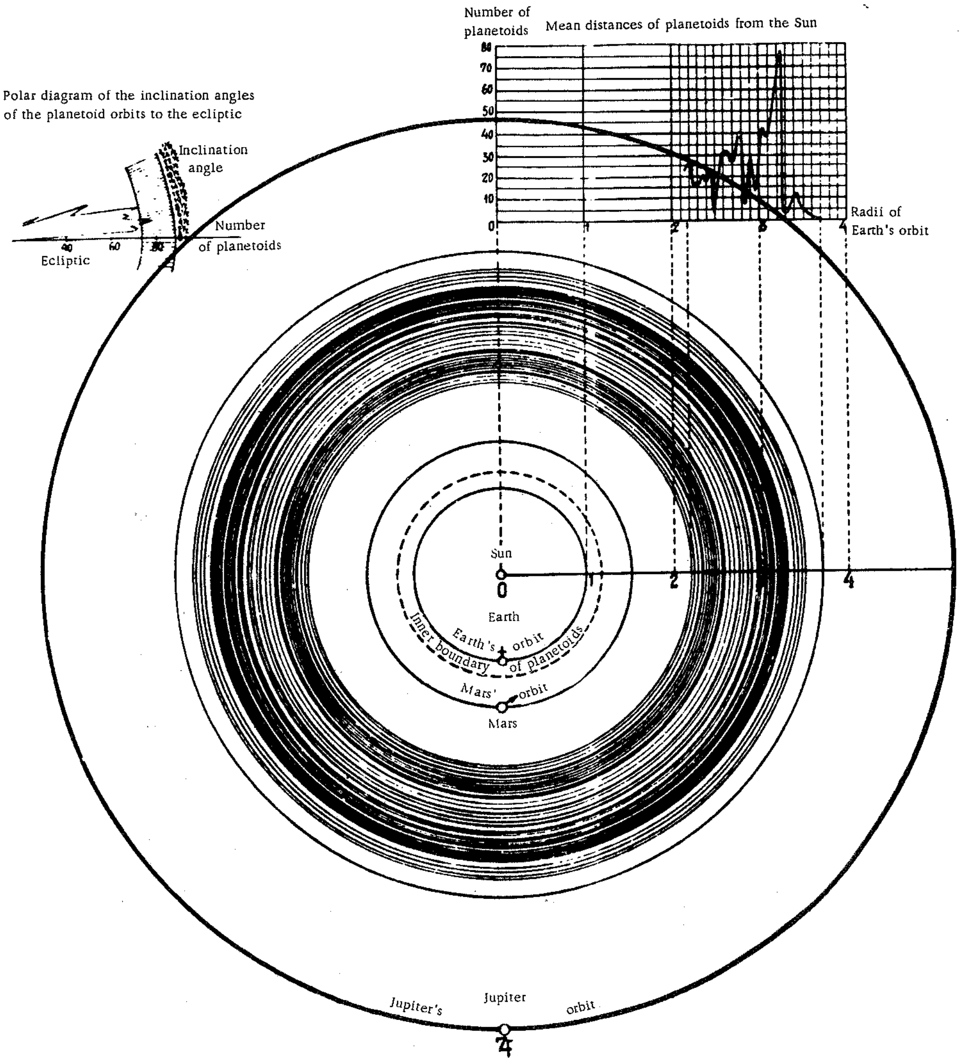
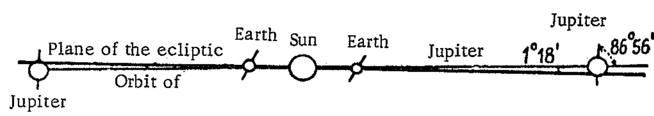


FIGURE 51. Planetoid orbits



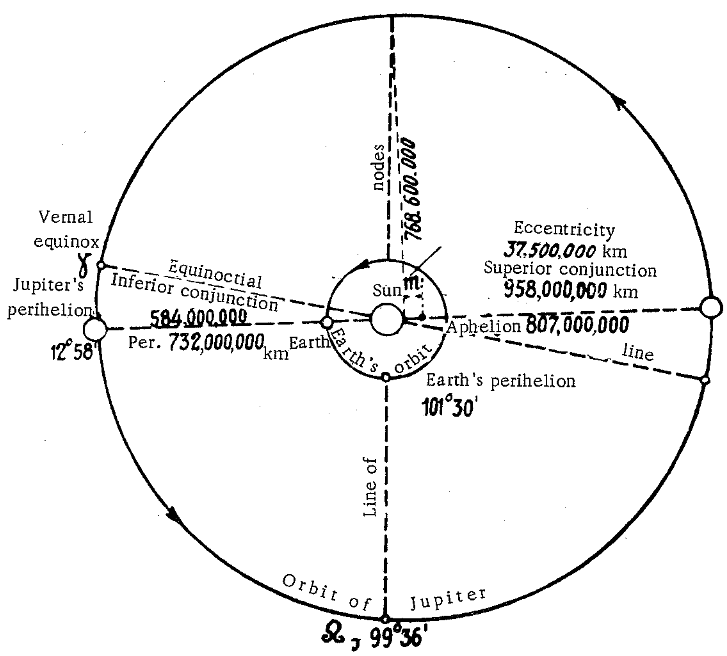


FIGURE 52. Orbit of Jupiter in orthogonal projection

(55)

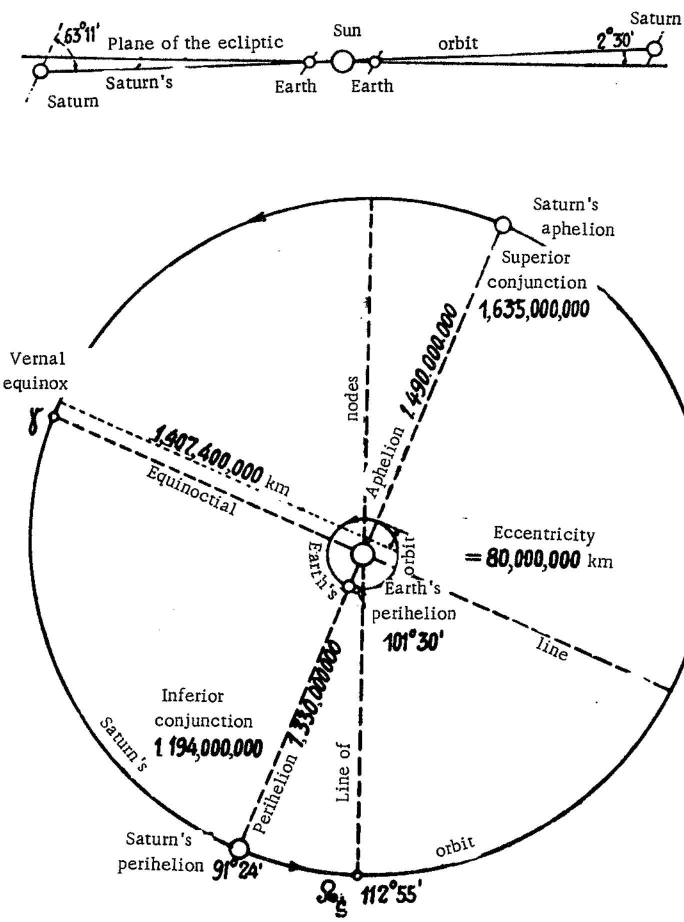


FIGURE 53. Orbit of Saturn in orthogonal projection

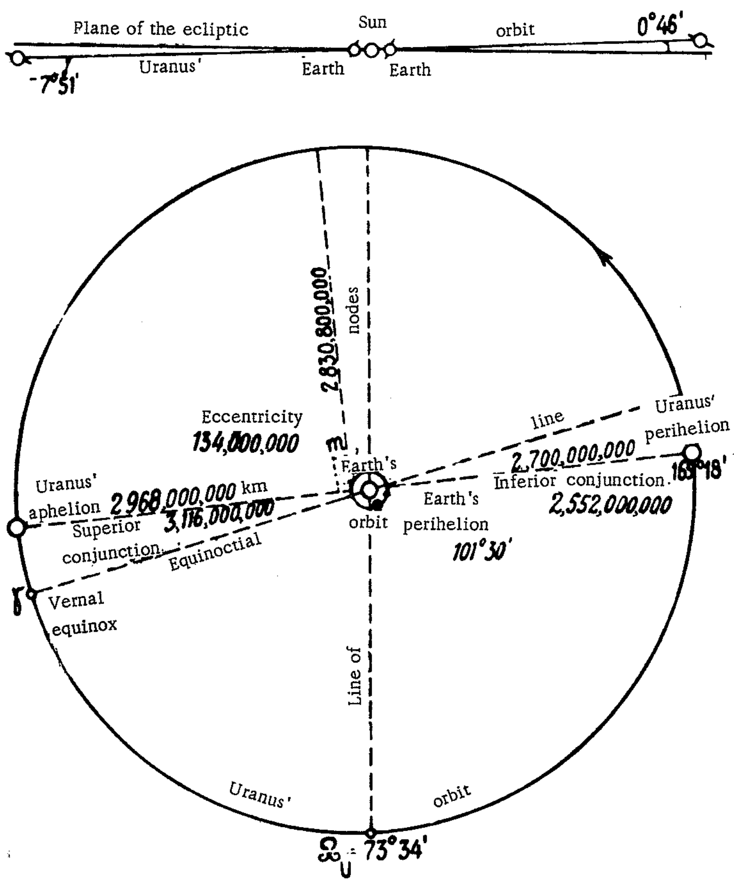


FIGURE 54. Orbit of Uranus in orthogonal projection

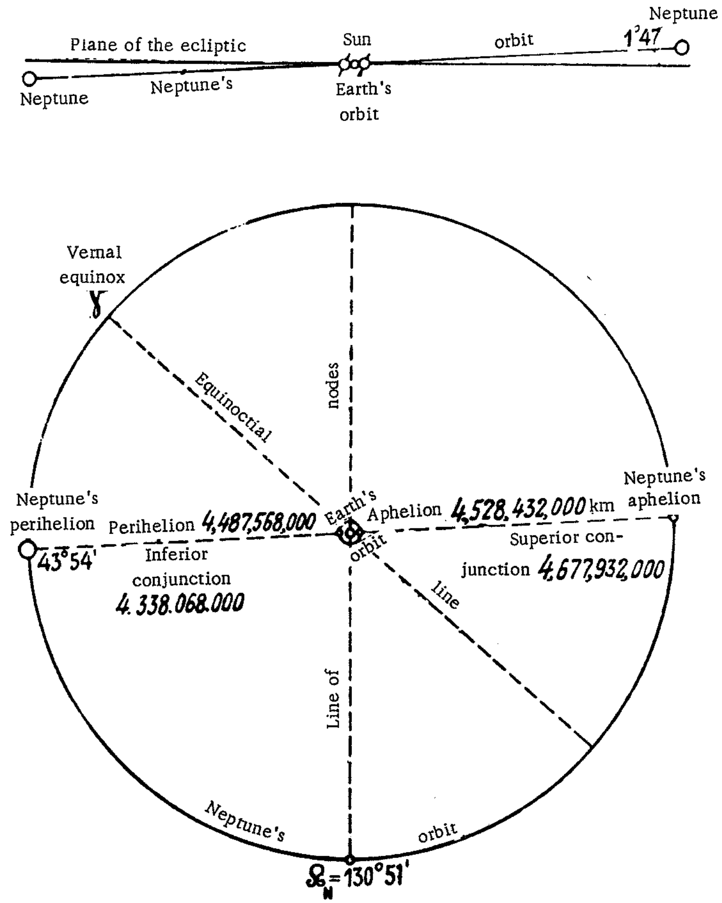


FIGURE 55. Orbit of Neptune in orthogonal projection

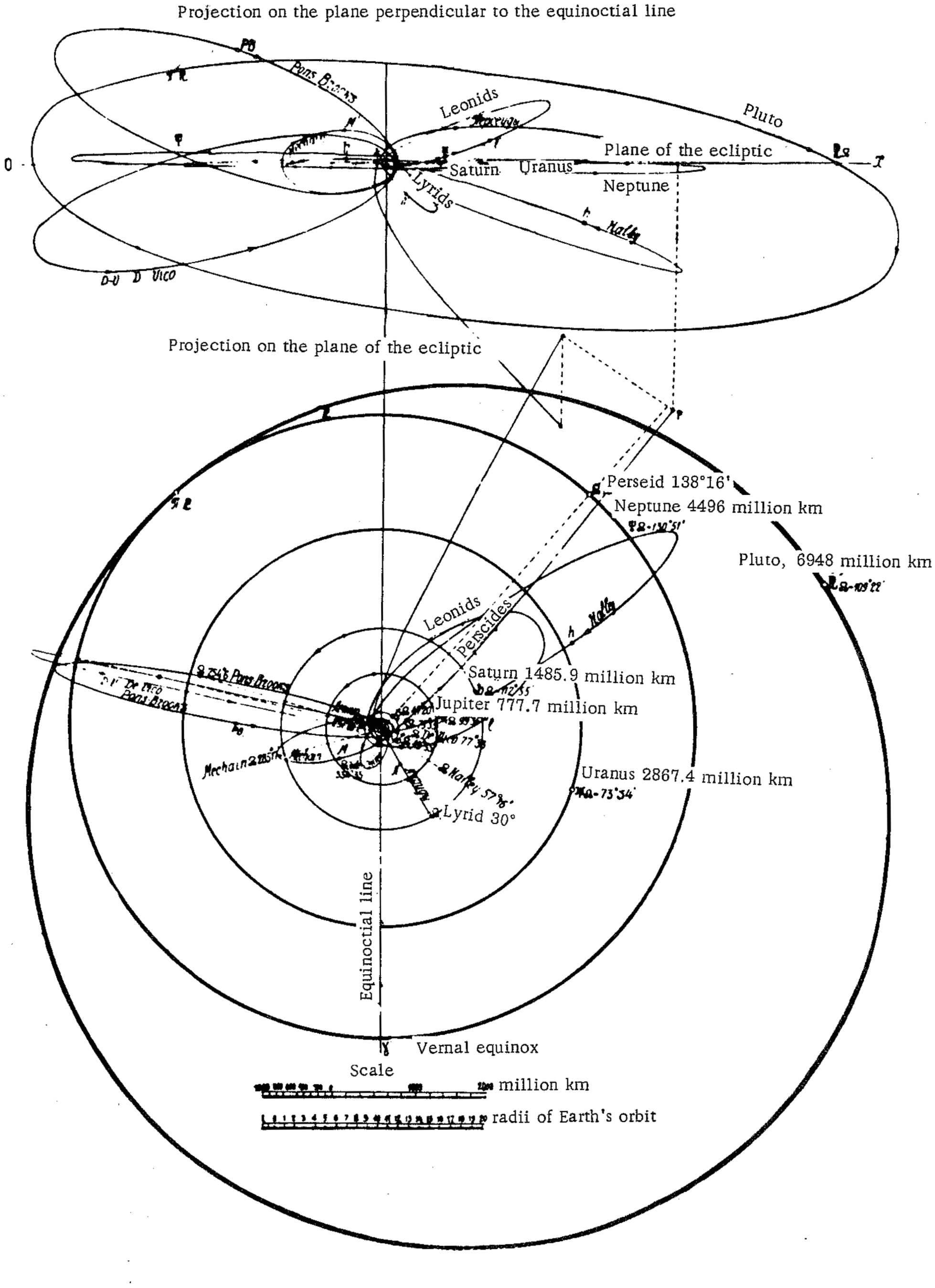


FIGURE 56. Orbits of the superior planets, comets, and meteorites in orthogonal projection

59 THE PATHS OF PLANETS

(Astronavigation chart)

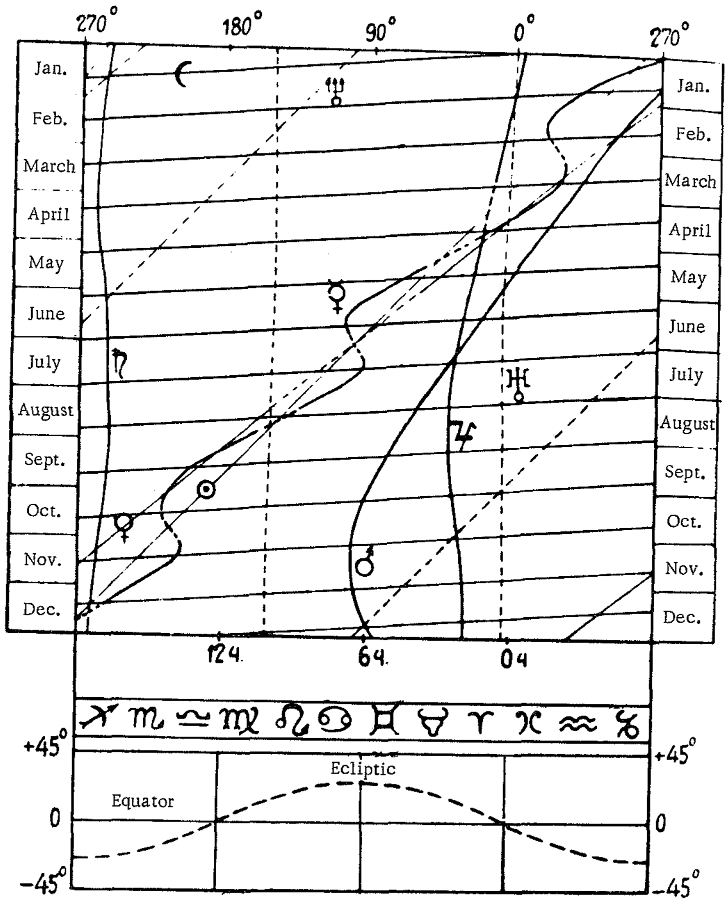
Special astronavigation charts will be needed for future space flights As an example, Figure 57 shows the map of the sky for 1928 showing the paths of the planets and their positions among the fixed stars for each day of the year. Figure 58 makes it possible to pinpoint the position of each planet at any time relative to the ecliptic, near which the orbits of the major planets lie.

The path of each planet in Figure 57 is marked by a wavy line. This is the line traced by the planet in the year 1928. For example, to find the position of Mars on 1 July 1928, place a ruler on the chart in Figure 57 so that it passes through the 1 July markings on both sides of the figure and note the point at which the ruler intersects the Mars curve. From this point drop a vertical to the middle figure (Figure 58); it will intersect the ecliptic at a point near which the planet will be observed at the relevant time.

(60)

57

58



FIGURES 57 and 58. Astronavigation charts

(62) TABLE 5. Satellites of the planets

(63)

Planet	Satellite	Orbit: Radius, mean, millions of km	Orbit: Radius, relative to equatorial radius of planet	Orbit: Eccentricity	Orbit: Inclination to planetary orbit
1	2	3	4	5	6
Mars	Phobos	0.00939	2.77	0.03208	equatorial planet
	Deimos	0.0236	6.95	0.0057	" "
Jupiter	Io	0.421	5.906		3°5'
	Europa	0.671	9.397		3°5'
	Ganymede	1.070	14.989	low	3°0'
	Callisto	1.881	26.364		2°41'
	5 [Amalthea]	0.181	2.54		—
	6 "	11.42	160	0.155	29°
	7 "	11.92	164	0.207	27°
	8 "	23.48	329	0.38	148° retrograde
	9 "	24.700	351	0.16	retrograde
Saturn	Mimas	0.189	3.07	0.019	29°7—26°5
	Enceladus	0.2424	3.94	0.005	28°1
	Tethys	0.3002	4.88	0.0009	28°10
	Dione	0.3838	6.24	0.0021	28°10
	Rhea	0.5364	8.72	0.0008	28°1
	Titan	1.2438	20.22	0.0279	27°37'
	Hyperion	1.5065	24.49	0.104	28°10'
	Iapetus	3.6237	58.91	0.0284	18°34'
	Phoebe	13.1648	214.4	0.166	20°(174°8') retrograde
	Themis	1.4886	24.17	0.23	39°1 "
Uranus	Ariel	0.187291	7.71	0.020	
	Umbriel	0.261139	10.75	0.010	east—west motion
	Titania	0.42827	17.63	0.0	
	Oberon	0.57256	23.57	0.0	
Neptune	Triton	0.37347	13.33	0.007	145° (138°6) east—west motion

Satellite's radius		Volume relative to planet	Density relative to Earth	Mass relative to planet	Orbital period around planet	
mean, km	relative to planetary radius				in sidereal Earth days	in planetary days
7	8	9	10	11	12	13
4.25	–	–	–	–	7h 39' 13"9	–
4.25	–	–	–	–	30h 17' 54"9	–
1,967	0.027	0.000020	0.198	0.000017	1d 18° 27' 33".5	4.27d
1,630	0.024	0.000014	0.374	0.000023	3d 13° 13' 42"	8.58d
2,850	0.040	0.000060	0.325	0.000088	7d 3° 42' 33".4	17.29d
2,180	0.034	0.000039	0.253	0.000042	16d 16° 32' 10".2	40.43
160	–	–	–	–	11° 57' 22".7	–
small	–	–	–	–	251 d	–
"	–	–	–	–	265 d	–
"	–	–	–	–	738.9 d	–
"	–	–	–	–	3 years	–
257	–	–	–	–	22° 37' 5".3	–
318	–	–	–	–	1d 8° 53' 6".8	–
495	–	–	–	–	1d 21° 18' 26".1	–
470	–	–	–	–	2d 17° 41' 9".5	–
612	–	–	–	1/4714	1d 12° 25' 12".2	–
1,222	–	–	–	–	15d 22hr 41' 27"	–
165	–	–	–	–	21d 6° 38' 23".9	–
422	–	–	–	–	79d 7° 56' 22".7	–
100	–	–	–	–	550d 10° 34'	–
61	–	–	–	–	20d 20hr 24	–
591	–	–	–	–	2d 12° 29' 20".9	–
400	–	–	–	–	4d 3° 27' 37".2	–
942	–	–	–	–	8d 16° 56' 29".5	–
875	–	–	–	–	13d 11° 7' 6".4	–
–	–	–	–	–	5d 21° 2' 38".4	–

The path of the Sun is marked by an oblique line extending from bottom left to top right. The path of the Moon is marked by several oblique lines, that of Mercury by a wavy line near the Sun, the path of Venus by a similar line, but with more gentle waves, Mars by a line with a single wave, Jupiter, Saturn, Uranus, and Neptune by slightly curved lines. Since the last 2 planets are invisible to the naked eye, their paths are marked by dashed curves. The dashed sections of the paths of other planets indicate that these planets are also invisible to the naked eye during the corresponding period.

(60)

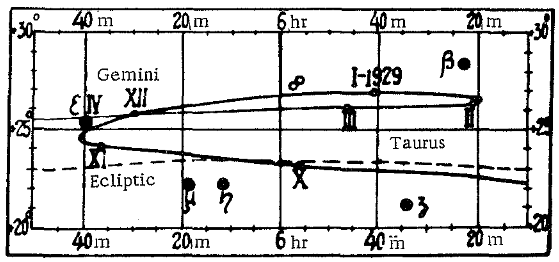


FIGURE 59. The apparent path of Mars in 1928 and 1929. Roman numerals identify the position of the planet on the 1st of each month; the symbol ∞ identifies opposition with the Sun

The points of the sky in opposition to the Sun are marked by a dashed line parallel to the Sun. At the point of intersection of this line with the path of a planet, the planet is in opposition to the Sun. Astronomical almanacs give detailed tables listing the coordinates of the planets in different times of the year (the hour angle or the direct ascension and the declination) and more detailed charts of the paths of planets (Figure 57). Figure 59 shows the path of Mars in 1928 and 1929. The coordinates of Mars for 1 July are as follows: right ascension 6.4 min, declination 11°13'.

61 SATELLITES OF THE PLANETS

All the superior planets have satellites. The characteristics of these satellites are listed in Table 5.

As an example, Figure 60 shows the orbits of the two satellites of Mars, Phobos and Deimos, in orthogonal projection. Note that the position of the satellite orbits relative to the planet orbit varies continuously because of the mutual gravitational perturbation. Figure 61 shows, among other orbits, the variable orbit of the eighth satellite of Jupiter. Figure 62 shows the displacement of one of the small satellites of Saturn, Hyperion, under the pull of the largest satellite, Titan.

(61)

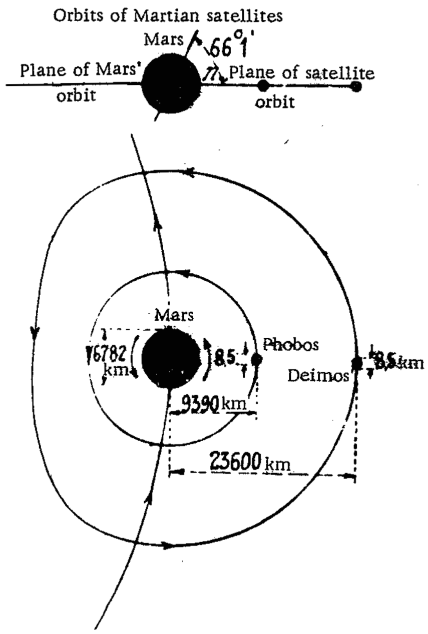


FIGURE 60. Orbits of the satellites of Mars in orthogonal projection

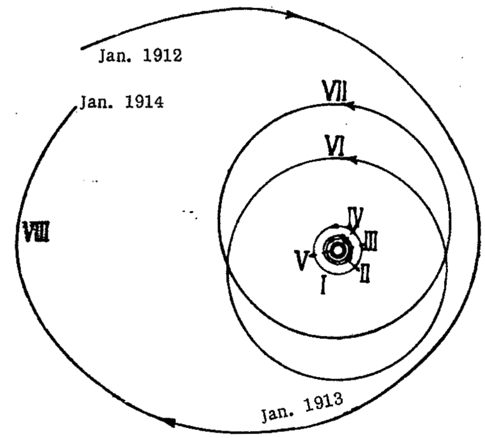


FIGURE 61. Orbits of the satellites of Jupiter

64

(61)

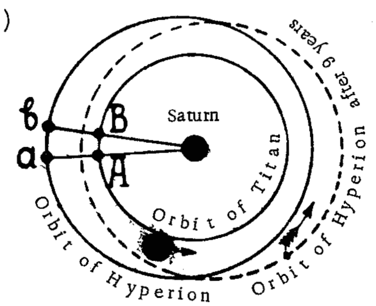


FIGURE 62. Orbits of the satellites of Saturn

COMETS

A typical comet consists of a head, a nucleus within the head, and a tail. So far, the orbits of some 400 comets have been determined, of which 100 are elliptical and the rest parabolic.

Comet Schwasssman-Wachman, discovered in 1927, is remarkable in that it apparently constitutes a transitional stage between comets and minor planets. Its entire orbit virtually coincides with a circle with a radius of some 960 million km (minor axis 955 million km, major axis 967 million km) and falls between the orbits of Jupiter and Saturn. In perihelion it approaches the Sun to a distance of 760 million km.

Table 6 lists the periodic comets, i.e., those which periodically trace a closed orbit reappearing at fixed intervals. This list was drawn up by N. I. Idel'son and originally published in "Ezhegodnik Russkogo Astronomicheskogo Obshchestva" ["Yearbook of the Russian Astronomical Society"], p. 55. 1923.

(66) (67)

TABLE 6. List of periodic comets

Comet	T (GMT)	P	lg q	e	ω	Ω	i	Last apparition	q'	a	b	f
Encke	1921 July 13.06	3ʸ.30	9.531	0.847	184°13'	334°351	12°31'	1921 IV	0.34	2.22	1.15	1.88
$Tempel_2$	1920 June 10.20	5.15	0.121	0.557	186 39	120 46	12 45	1920 (9,c)	–	–	–	–
$Tempel_3$ – Swift .	1890 Oct. 4.52	5.68	0.062	0.638	113 41	290 19	5 27	1908 II	–	–	–	–
Brorsen	1890 Feb. 24.10	5.46	9.769	0.810	14 56	101 28	29 44	1879 I	–	–	–	–
Winnecke	1921 June 13.33	4.66	0.015	0.628	171 50	96 33	18 12	1921 II	–	–	–	–
de Vico-Swift . .	1901 Feb. 13.67	6.40	0.223	0.516	324 6	24 51	3 35	1894 IV	–	–	–	–
Perrine	1922 Dec. 25.2	6.59	0.079	0.659	167 15	242 18	15 43	1922 f	–	–	–	–
Giacobini	1913 Nov. 2.07	6.51	9.989	0.720	171 30	195 52	30 44	1931 V	–	–	–	–
$Tempel_1$	1898 Oct. 3.97	6.54	0.320	0.402	168 40	72 36	10 47	1879 III	2.09	3.49	3.20	1.40
d'Arrest	1910 Sept. 16.05	6.54	0.104	0.637	173 47	146 22	15 47	1910 III	–	–	–	–
Finlay	1919 Oct. 17.24	6.66	0.013	0.715	318 42	44 40	4 04	1919 II	–	–	–	–
Wolff	1918 Dec. 13.52	6.78	0.199	0.559	172.57	206 42	25 17	1918 V	–	–	–	–
Holmes	1913 Jan. 20.69	6.86	0.327	0.412	14 18	331 50	20 49	1906 III	2.12	3.61	3.29	1.49
Borelly	1918 Nov. 16.68	6.90	0.146	0.615	352 23	77 01	30 29	1918 IV.	–	–	–	–
$Brooks_2$	1911 Jan. 8.35	7.11	0.293	0.469	343 31	18 13	6 4	1911 I	1.96	3.69	3.26	1.73
Faye	1910 Nov. 1.46	7.44	9.219	0.566	199 17	206 15	10.36	1910 V	0.17	0.39	0.32	0.22
Kopff	1919 June 28.21	6.58	0.231	0.515	19 44	263 49	8 42	1919 I	–	–	–	–
Schorr	1918 Sept. 27.58	6.74	0.276	0.472	278 8	117 57	5 35	1918 III	1.89	3.58	3.15	1.69
Schoumasse . . .	1919 Oct. 31.23	8.00	0.085	0.696	45 36	91 19	15 18	1919 IV	1.22	4.01	2.89	2.79
Neujmin	1916 Mar. 11.23	5.50	0.128	0.570	193 43	327 31	10 40	1916 II	–	–	–	–
Taylor	1916 Jan. 30.91	6.37	0.193	0.546	354 48	113 54	15 32	1916 I	–	–	–	–
Daniel	1909 Nov. 28.72	6.48	0.140	0.602	3 29	71 0	19 27	1909 IV	1.38	3.46	2.89	2.08
Metcalf	1906 Oct. 10.76	7.59	0.212	0.578	200 42	194 19	14 31	1906 VI	1.63	3.86	3.16	2.23
Mechain	1912 Oct. 29.47	13.5	0.013	0.818	178 57	285 17	58 09	1912 IV	1.03	5.65	3.24	4.62
Neujmin	1913 Aug. 16.52	17.56	0.184	0.774	346 17	347 54	14 29	1913 III	–	–	–	–
Westphal	1913 Nov. 26.27	61.73	0.098	0.920	570 4	346 27	40 52	1913 VI	–	–	–	–
Pons-Brooks . . .	1884 Jan. 25.27	71.56	9.890	0.955	199 12	254 6	74 3	1884 I	0.77	17.11	5.73	16.34
Olbers	1887 Oct. 8.48	72.65	9.079	0.931	65 20	84 32	44 34	1887 V	–	–	–	–
Halley	1910 Apr. 19.68	76.02	9.769	0.967	111 43	57 16	162 13	1910 II	0.59	17.87	4.55	17.18
Brorsen	1919 Oct. 16.27	69.63	9.691	0.971	129 31	310 47	19 12	1919 III	–	–	–	–
de Vico	1846 Mar. 5.55	75.13	9.822	0.963	12 53	77 33	85 6	1846 IV	0.664	17.97	4.82	17.28

The following symbols are used in the table: T — time of perihelion passage; P — orbital period in years; q — perihelion distance; a — semimajor axis; b — semiminor axis; f — focal distance; e — eccentricity ($e = f/a$); ω — distance from perihelion to node; Ω — ascending node on the ecliptic; i — inclination to the ecliptic. The Roman numerals under "last apparition" correspond to the definitive numeration of the comets.

The cometary orbits lie at different angles to the plane of the ecliptic. Using the data of Table 6, we have drawn in Figure 56 the orbits of some comets in orthogonal projection.

The perihelia of the orbits of some comets are only a few hundred thousand kilometers distant from the Sun. About 25 comets pass inside the orbit of Mercury; nearly 3/4 of all the comets pass inside the Earth's orbit; very few of the previously observed comets permanently move beyond the orbit of Mars and all the known comets lie inside the orbit of Jupiter.

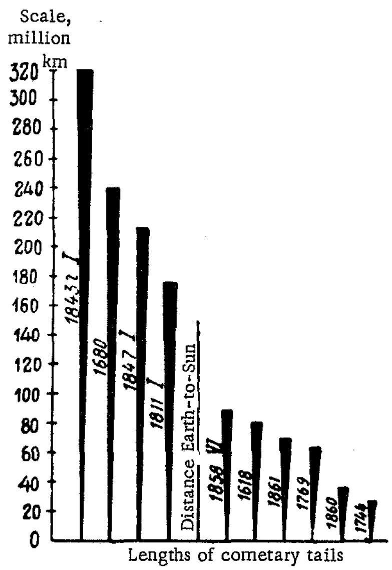


FIGURE 63.

Table 7 lists the periodic comets whose apparitions have not been observed since 1882. We see from the table that the periods of some comets are as long as 2,801,864 years. Flammarion believes that there are billions of comets. They reach tremendous velocities, especially in perihelion, when they move with
65 speeds of up to 560 km/sec (No. 15 in Table 7) and even 885 km/sec (Halley). The head of the comet can be 15,000 km in diameter and larger, but the nucleus may be quite small, possibly not exceeding 150 km in diameter. The cometary tails are astonishingly long. The tail cross section near the head reaches thousands and tens of thousands of kilometers, gradually opening up to a width of hundreds of thousands of kilometers at the end. The length of the tails ranges from a few million to hundreds of millions of kilometers (Figure 63). The masses of comets are negligibly small, and they are unable to perturb the motion of planets and satellites.

Comets are grouped in two families. Comets of type I follow almost identical paths. For example, there is a group of comets approaching the Sun from the part of the sky around Sirius.

Comets of type II have their aphelia near the planetary orbits. There is a Jupiter family (30 comets), a Saturn family (2 comets), a Uranus family (3 comets), a Neptune family (6 comets), etc.

TABLE 7. Periodic comets not observed between 1882 and 1928

	Comet	Aphelion distance in radii of Earth's orbit	Orbital period in years	Next probable apparition
1	Comet 1866	19	33 yr 64 d	1899
2	1867 I	19	33 yr 228 d	1900
3	1846 I	28	55 d	1902
4	1873 II	29	55	1928
5	1852 II	32	69	1922
6	1812	33	71	1822
7	1846 III	34	37	1919
8	1815	34	74	1887
9	1847 V	35	75	1922
10	1862 III	49	121	1983
11	1532, 1661	48	129	1919
12	1852 I	65	188	2041
13	1845 III	78	249	2094
14	1840 IV	97	344	2184
15	1843 I	104	376	2219
16	1846 VI	108	401	2247
17	1861 I	110	415	2276
18	1861 II	112	422	2283
19	1793 II	111	422	2215
20	1746	127	515	2261
21	1840 III	163	743	2583
22	1811 II	181	875	2686
23	1860 III Groneman	211	1,060	2860
24	1807	286	1,714	3521
25	1858 III	311	1,950	3808
26	1858 III Donati	–	1,880	–
27	1769	327	2,090	3859
28	1827 III	379	2,611	4438
29	1846 I	388	2,721	4567
30	1811 I	421	3,065	4876
31	1763	434	3,196	5150
32	1873 IV	480	3,277	5629
33	1840 II	505	3,789	4959
34	1825 III	535	4,386	6211
35	1864 II Tempel	563	4,738	6602
36	1822 III	618	5,649	7471
37	1858 VIII Tuttle	–	6,000	–
38	1849 III	813	8,375	10,224
39	1857 III Klinkerfues	–	7,040	–
40	1680	855	8,813	10,493
41	1846 Hind	–	10,818	–
42	1840 II	1,053	13,866	15,706
43	1847 IV	2,489	43,954	15,801
44	1780 I	3,975	75,838	77,618
45	1844 II	4,367	102,050	103,894
46	1863 I	29,989	1,840,000	1,841,863
47	1864 II	40,485	2,800,000	2,801,864

69 SHOOTING STARS

"Shooting stars" are fragments of various objects penetrating into the Earth's atmosphere from outer space and sometimes hitting the ground. Table 8 lists some characteristics of these objects.

TABLE 8. Shooting stars

	Designation	Origin	Composition	Incidence on the ground	Orbit	Size or weight	Velocity, km/sec	Epoch of encounter with Earth
Shooting stars (small objects) up to streams of 3,000	Perseids Leonids Andromedads Lyrids Orionids	Cometary	Small objects reaching the ground as dust	$146 \cdot 10^9$	Parabola or ellipse	up to $1\ mm^3$	42–72 km/sec	10 Aug. 14 Nov. 24 Nov. 20 Apr. 20 Oct.
Large objects	Bolides, meteors, meteorites, aerolites, uranolites	Planetary and cometary	Often identical to terrestrial rocks	—	Various	up to 15 ton	up to 79 km/sec	—

Small-sized objects entering the Earth's atmosphere fuse and burn up, reaching the ground in the form of dust. If these objects are sufficiently large, they leave a fiery trail in the atmosphere, hitting the ground as a substantial lump of rock.

Orbits of shooting stars

Figure 56 shows in orthogonal projection the orbits of the Perseids, Leonids, and Lyrids, based on the data of Table 9 borrowed from I.A.Kleiber, "Astronomicheskaya teoriya padayushchikh zvezd" [Astronomical Theory of Shooting Stars], St. Petersburg, p. 98. 1884. The orbital elements of comets which virtually coincide with those of the shooting stars are also given.

(70)
TABLE 9. Orbital elements of shooting stars and comets

Elements	Perseids, 10 Aug.	Comet 1862 I	Leonids, 14 Nov.	Comet 1866 I	Lyrids, 20 Apr.	Comet 1861
Longitude of the node Ω	138° 16'	137° 27'	231° 28' 2	231° 26' 1	30°	30°
Inclination of the orbit i	116° 57'	113° 34'	163° 15' 5	162° 42'	89°	80°
Longitude of perihelion n	343° 38'	344° 41'	303° 34' 1	299° 32'	236°	243°
Perihelion distance π . .	0.9643	0.9626	0.9873	0.9765	0.956	0.921
Orbital period T	108 ?	121.5	33.25	33.176	—	—
Eccentricity e	—	—	0.9046	0.9054	0.9829	0.9835
Semimajor axis a	—	—	10.340	10.324	5.58	5.58
Orbit	—	—	ellipse	ellipse	—	—

There are also numerous other orbits, corresponding to other meteor streams. Their nodes Ω range from 0°—360°, π varies from 0°—360°, i from 0°—90°, and q from 0—1.967. In other words, the Earth is sprayed with streams of shooting stars from all directions.

70 The peak incidence of shooting stars is observed at altitudes of some 100 km. The velocity of motion is on the average 48 km/sec.

SHADOW CONES OF PLANETS

An interplanetary craft traveling in outer space may enter the shadow cone cast by a planet. In other words, a solar eclipse produced by the particular planet will be observed on board. Figure 64 shows the geometry of illumination of a planet by the Sun. The length of the shadow cone is L. If both the planet and the Sun are regarded as perfect spheres, the shadow cast by the planet is indeed a cone. Adjacent to the total shadow, known as the umbra, there is an area of part shadow—part light, known as the penumbra (diagonal hatching in Figure 64). Table 10 lists the lengths of the shadow cones cast by different planets.

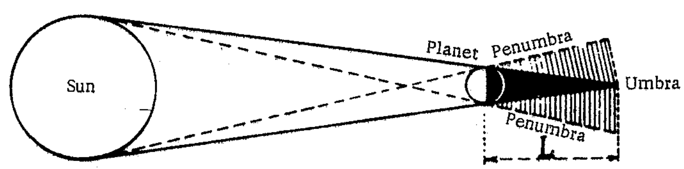


FIGURE 64. Shadow of a planet

72 TABLE 10. The length L of the shadow cone cast by a planet

Planet	Length of shadow L
Mercury	200,860 km
Moon	380,000 "
Venus	955,659 "
Mars	1,119,030 "
Earth	1,390,000 "
Jupiter	88,000,000 "
Uranus	103,000,000 "
Saturn	138,000,000 "
Neptune	187,000,000 "

Note, however, that the Sun is not a perfect sphere, nor is the planet, so that the shadow will deviate from a perfect cone. Figure 65 illustrates schematically the construction of the shadow surface in orthogonal projections for an ellipsoidal planet unrealistically close to the Sun. The surface enveloping the Sun and the planet in this case has 3 generatrices. The shape of the different cross sections of the shadow surface is shown

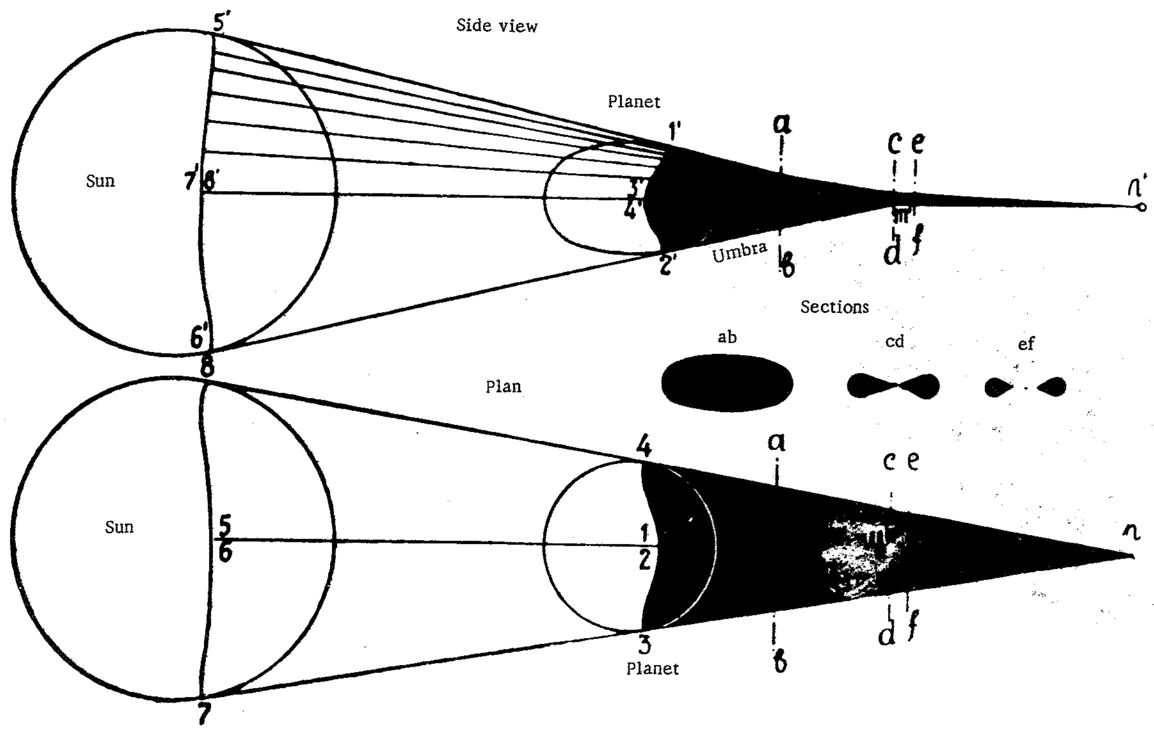


FIGURE 65. A planetary eclipse

in the figure. Thus, a spacecraft emerging from the shadow (section along ef) may in certain cases reenter the shadow of the same planet on its forward course (Figure 66).

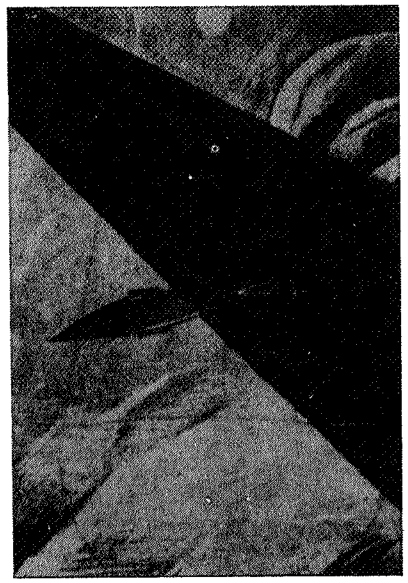


FIGURE 66. Spacecraft entering the shadow cone of a planet

73 THE STELLAR UNIVERSE

You are staring greedily into the distance; from the top of a hill
You follow the stars, recognizing and counting them,
Predicting their orbit, inclinations. . . . You are thinking,
And the cosmic secrets become clearer to the mind.

Heavenly shepherd! In quiet and darkness
You heard the names, you saw the light:
You were the first to chart the paths of your planets,
Find names for the signs of the zodiac.

V.Bryusov, "Khaldeiskii pastukh" ["Chaldean Shepherd"]

STARS

What can you say about them, about the luminous stars?
Why do we love their radiant stones,
Follow their pale light through darkened air?

Translated by V. Bryusov, "Zvezdy" ["Stars"]

THE BIG DIPPER

The fairy of the northern night,
You, the Big Dipper,
Caress tired eyes,
Blot out painful dreams.

V. Bryusov

The stellar universe (Figure 67) is infinite. We can hardly expect to be able to count all the stars, which according to Flammarion number hundreds of millions.

Approximate star counts give the following results

1st	magnitude	14
10th	"	379,000
16th	"	57,000,000

The distance from the Earth to the stars is generally measured in light years or parsecs.* Stars have their own proper motions and move with different velocities.

(74)

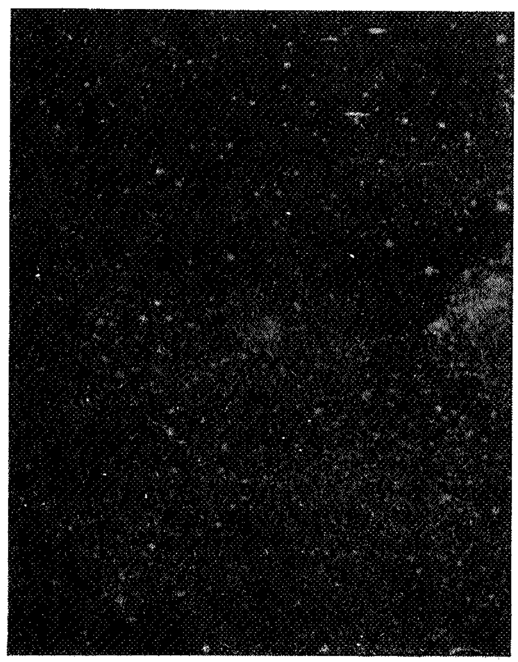


FIGURE 67. The stellar universe. Part of the Milky Way

The proper motions of stars are decomposed into components: the radial motion (toward the Earth or away from the Earth) and the motion in the direction of the Earth's orbit. S. Newcomb gives velocities from 3 km/sec (the Polar Star) to 305 km/sec (AGC 10534) for velocities in the direction of the Earth's orbit. For the radial velocities, F. Moulton gives the following limits: (+ for velocities away from the Earth, − for velocities toward the Earth); −3 km/sec (Antares),

* One parsec = $32.2 \cdot 10^{12}$ km = 3.3 light years.

−32.8 km/sec (Altair), +1.9 km/sec (Spica in Virgo), +54.7 km/sec
(Aldebaran). The motion of stars is also measured according to their
74 angular displacement over the sky in one year. For some stars this
displacement may reach 8.7 sec of arc.

The proper motion of stars changes the general configuration of constellations, but the change will be noticeable only over long periods of time. Figure 68 shows the Great Dipper 100,000 years ago, at present, and 100,000 years in the future. The arrows in the middle figure show the direction of motion of the individual stars in this constellation.

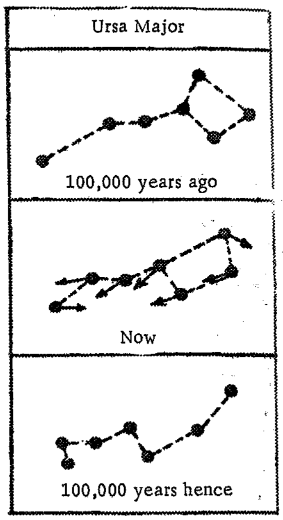


FIGURE 68. Changes in the shape of the Great Dipper

Table 11 lists the distances of some stars from the Earth. We see from the table that the light will be able to cover these interstellar distances in 4.3—165 years. There are, however, stars at much greater distances from the Earth, and their light takes tens of thousands of years to reach the observer.

The sizes of star clusters and the
velocities of their motion in space are
truly tremendous. For example, the
globular cluster in Hercules has a dia-
meter of over 350 light years and it moves
75 with a speed of 300 km/sec. The light of
other nebulae takes 8—10 million years
to reach the Earth, and the nebulae them-
selves move with velocities of up to 1,800
km/sec (NGC 584, for example).

TABLE 11. Distances of stars from the Earth

Star	Distance from Earth		
	in light years	in radii of Earth's orbit	in 10^{12} km
Proxima Centauri	3.6	228,000	33.8
α - Centauri	4.3	272,000	40.3
Lalande 21185	6.4	405,000	59.9
β - Centauri	6.5	411,000	60.8
α - Canis Majoris	8.0	506,000	74.9
Σ - Draconis 2392	9.32	589,000	87.2
Sirius	9.88	625,000	92.5
α - Canis Minoris	10.0	632,000	93.5
Groombridge 34	10.5	664,000	98.3
61 Cygni	11.0	695,000	102.9
Lacaille 9352	11.24	711,000	105.2
Procyon	12.0	759,000	112.3
Lalande 21258	12.5	790,000	116.9
Aeltzen 11677	12.5	790,000	116.9
σ - Draconis	13.2	834,000	123.4
Aldebaran	13.8	872,000	129.0
α - Aquilae	14.0	885,000	130.9
ϵ - Indi	14.4	910,000	134.7
Castor	15.7	993,000	147.0
Aeltzen 17415	16.3	1,030,000	152.4
1516 Draconis	17.1	1,081,000	160.0
o^2 - Eridani	17.1	1,081,000	160.0
Altair	17.1	1,081,000	160.0
Bradley 3077	17.1	1,081,000	160.0
ζ -Herculis	19.0	1,201,000	177.7
70 Ophiuchi	19.0	1,201,000	177.7
η -Cassiopeiae	20.1	1,271,000	188.1
Vega	21.7	1,372,000	203.1
ι - Canis Majoris	24.25	1,533,000	226.9
Capella	29.6	1,871,000	276.9
α - Tauri	30.0	1,897,000	280.8
Arcturus	34.7	2,194,000	324.7
γ - Draconis	35.0	2,213,000	327.5
Polaris	36.6	2,314,000	342.5
α - Aurigae	41.0	2,592,000	383.6
α - Lyrae	41.0	2,592,000	383.6
α - Bootis	50.0	3,161,000	467.8
μ - Cassiopeiae	54.4	3,439,000	509.0
β - Geminorum	55	3,477,000	514.6
85 Pegasi	64.5	4,078,000	603.5
Groombridge 1830	72.5	4,583,000	678.3
α - Orioni	165.4	10,431,000	1,543.8
α - Leonis	165.0	10,431,000	1,543.8
Orion Nebula	600.4	—	6,000.0
Cluster in Hercules . . .	36,000	$2{,}286 \cdot 10^7$	350,000.0
Cluster NGC 7006	217,000	—	—
Spiral nebulae	325,000 – 10,000,000	—	—
Radius of curvature of Einstein's bounded universe	170,000,000	—	—

Table 12 has been borrowed from the Journal of the Canadian Royal Astronomical Society. It shows the comparative dimensions of objects from subatomic particles to the entire Universe.

TABLE 12

Class	Dimensions		Examples
−9	0.000 000 000 000 06 inch	$1.6 \cdot 10^{-13}$ cm	Electron
−8	0.000 000 000 006 in.	$1.6 \cdot 10^{-11}$ "	—
−7	0.000 000 006 in.	$1.6 \cdot 10^{-9}$ "	—
−6	0.000 000 06 in.	$1.6 \cdot 10^{-7}$ "	Atom
−5	0.000 006 in.	$1.6 \cdot 10^{-5}$ "	Soap bubble
−4	0.000 6 in.	$1.6 \cdot 10^{-3}$ "	Thinnest tissue paper
−3	0.06 in.	$1.6 \cdot 10^{-1}$ "	—
−2	6.3 in.	$1.6 \cdot 10$ "	—
−1	0.01 mile	$1.6 \cdot 10^{3}$ "	—
0	1 mi.	$1.6 \cdot 10^{5}$ "	—
1	100 mi.	$1.6 \cdot 10^{7}$ "	—
2	10,000 mi.	$1.6 \cdot 10^{9}$ "	Earth
3	1,000,000 mi.	$1.6 \cdot 10^{11}$ "	Earth — Moon system
4	100,000,000 mi.	$1.6 \cdot 10^{13}$ "	Earth — Sun system
5	10,000,000,000 mi.	$1.6 \cdot 10^{15}$ "	Solar system
6	1,000, 000, 000, 000 mi.	$1.6 \cdot 10^{17}$ "	—
7	17 light years	$1.6 \cdot 10^{19}$ "	Nearest star
8	1,700 l.yr.	$1.6 \cdot 10^{21}$ "	Star cluster
9	170,000 l. yr.	$1.6 \cdot 10^{23}$ "	Galaxy
10	17,000,000 l. yr.	$1.6 \cdot 10^{25}$ "	Nearest spiral
11	1,700,000 l. yr.	$1.6 \cdot 10^{27}$ "	—
12	170,000,000,000 l. yr.	$1.6 \cdot 10^{29}$ "	Einstein's universe

77 *Chapter II*

THE ARMOR OF GRAVITY

INTRODUCTION

The main barrier preventing free interplanetary travel is the force of gravity chaining the spacecraft to the planet of origin. Once the spacecraft has managed to pierce this "armor of gravity" and escape into outer space, the pilot, by clever maneuvering and navigation, will be able to utilize the gravitational fields to his advantage for further advances into the realms of interplanetary space.

It is therefore essential to master the laws of gravitation and the equations of motion of objects in space under the effect of gravitational forces.

The first step toward piercing the "armor" is to learn how to overcome the Earth's gravitation or at least how to attenuate its force.

The force of terrestrial gravitation can be overcome in 3 different ways.

1. By screening the object from gravitation, as if paralyzing the force. So far, this mode of action is unfeasible, although science-fiction writers widely resort to this technique. The various methods of screening invented by novelists are described in Issue 2 of the series (Chapter 2).

2. By attenuating the force of gravitation. The Earth's gravitation can be lowered by reducing the density of the terrestrial rock material and thus increasing the volume of the planet. As a result, the new surface will lie farther away from the Earth's center, and because of the prevailing law of inverse squares, the gravitational forces at this surface will be lower than before. Unfortunately, this is again an impracticable solution, although geological evidence does seem to indicate that in certain eras in the past the volume of the planet was somewhat larger than it is now.
The same result can be achieved by launching the spacecraft from the equator, and not from the poles; the Earth has a slight equatorial bulge and it is conversely flattened at the poles. The gravitational forces are thus slightly weaker at the equator than at the poles. A similar effect is accomplished by moving the launching path from a valley to a mountaintop.
Another method of reducing the gravitational force is by harnessing the centrifugal forces of the Earth's axial rotation. The centrifugal forces
78 are zero at the poles and reach their maximum value at the equator, where they reduce the weight of objects by 1/290. A combination of both these factors will reduce the weight of objects at the equator by almost 0.5%.

To achieve weightlessness at the equator, the Earth would have had to be made to spin faster by a factor of $\sqrt{290} = \backsim 17$ (since the centrifugal force is proportional to the square of the velocity). A certain acceleration could be attained with the aid of the technique described by Hohmann in his "Die Erreichbarkeit der Himmelskörper," i.e., by making all the animals, trains, steamers, and other kinds of transport move along the parallels or along the equator from east to west; the reaction force would speed up the west-to-east rotation of the Earth, but the resulting acceleration would naturally be negligible.

3. By counteracting the force of gravity with the force of an explosion or with some other kind of mechanical energy.

THE LAW OF GRAVITATION

The motion of celestial bodies and their interaction are described by the the following laws.

Kepler's laws.

1. Planets and periodic comets move in elliptical orbits around the Sun, with the Sun occupying one of the foci of the ellipse. Note that in most applied problems, the orbits of planets (though not of comets!) may be treated as circles.

2. The area spanned by the radius-vector of an orbit is proportional to the time of motion of the radius-vector.

3. The square of the orbital period of planets around the Sun is proportional to the cube of the distance from the Sun.

Let T_1 and T_2 be the orbital periods of two planets; r_1 and r_2 their respective distances from the Sun. We may then write

$$\frac{T_1^2}{T_2^2}=\frac{r_1^3}{r_2^3}. \quad (1)$$

If the orbits are circular and the corresponding orbital velocities of the planets are V_1 and V_2, we have

$$T_1=\frac{2\pi r_1}{V_1} \quad \text{or} \quad T_2=\frac{2\pi r_2}{V_2}.$$

Kepler's third law thus gives

$$\frac{r_1^2}{V_1^2}\cdot\frac{V_2^2}{r_2^2}=\frac{r_1^3}{r_2^3} \quad \text{or} \quad \frac{V_2^2}{V_1^2}=\frac{r_1}{r_2}. \quad (2)$$

i.e., in circular orbits, the square of the orbital velocity of a planet is inversely proportional to the radius of the orbit. Let us apply Kepler's
79 third law to determine the time for a planet to fall on the Sun. If the Earth were to fall on the Sun, its orbit could be regarded as a highly elongated ellipse (Figure 69). Writing L for the distance of the Earth from the Sun, T for the normal orbital period of the Earth around the Sun, and t for the time of fall, we write

$$\frac{(2t)^2}{T^2}=\frac{(L/2)^3}{L^3},$$

whence

$$t=\frac{T}{\sqrt{32}}=\frac{365}{\sqrt{32}}=64 \text{ days},$$

i. e., the time for a satellite to fall on its primary is equal to the orbital period around the primary divided by 5.6.

The Moon will thus take $(27.3)/(5.6) = 5$ days to fall to the Earth.

Newton's law.

The attraction force between two objects is directly proportional to their masses and inversely proportional to the square of the distance between them.

Let the masses of two objects be m_1 and m_2; the distance between them is r. The force of attraction is then given by

$$F=\frac{k^2 \cdot m_1 \cdot m_2}{r^2}. \tag{3}$$

where k^2 is a proportionality coefficient, known as the universal gravitational constant.

Note that the dimensions of k^2 are $M^{-1} \cdot L^3 \cdot T^{-2}$, we see from (3):

$$k^2=\frac{F \cdot r^2}{m_1 \cdot m_2}=\frac{M \cdot V \cdot L^2}{MM}=\frac{L^3}{T^2 M}=M^{-1} L^3 T^{-2} \tag{4}$$

Determination of k^2.

When an object moves in a circular orbit, the centrifugal force of its circular motion $\frac{v^2}{r}$ is exactly balanced by the gravitational attraction of the primary

$$F=-m \cdot \frac{v^2}{r} \tag{5}$$

where m is the mass of the orbiting object, v is the velocity of its circular motion, and r the distance from the center of gravity.

For two objects orbiting around a common center of gravity we have from (2) and (5)

$$\frac{F_1}{F_2}=\frac{\frac{m_1 \cdot v_1^2}{r_1}}{\frac{m_2 v_2^2}{r_2}}=\frac{m_1 v_1^2 \cdot r_2}{m_2 \cdot v_2^2 r_1}=\frac{m_1 \cdot r_2^2}{m_2 r_1^2}=\frac{\frac{m_1}{r_1^2}}{\frac{m_2}{r_2^2}} \tag{6}$$

i. e., the gravitational forces are proportional.

80 Writing k^2 for the proportionality coefficient, which is the universal gravitational constant, we find

$$F=-k^2 \cdot \frac{m}{r^2}. \tag{7}$$

From (5) and (7) we thus have

$$k^2 \frac{m}{r^2}=m \frac{v^2}{r},$$

whence

$$k^2=v^2 \cdot r \tag{8}$$

i. e., the gravitational constant is equal to the square of the circular velocity of the object around the center of gravity multiplied by the radius of the orbit.

Setting $r = 1$ for the distance of the Earth from the Sun, we find from (8)

$$k^2 = v^2.$$

The length of the Earth's orbit is $2\pi r = 2\pi$.

The orbital period of the Earth around the Sun is 365 days. Thus,

$$v = \frac{2\pi}{365}$$

and

$$k^2 = \left(\frac{2\pi}{365}\right)^2 = (0.0172021)^2 \cdot (\log k = \bar{2}.23558)$$

expressed in astronomical units (i. e., time measured in days, length in units of the Earth's orbital radius, and mass in units of the solar mass).

To convert to kilometers and seconds, we take $r = 149 \cdot 10^6$ km, 1 day $= 864 \cdot 10^2$ sec, and from (4) we find for the Earth and the Sun

$$K^2 \, \mathrm{km/sec} = \frac{k^2 \cdot L^3}{T^2} = \frac{(0.0172021)^2 \cdot 149^3 \cdot 10^{18}}{864^2 \cdot 10^4} = 132 \cdot 10^9 \, \frac{\mathrm{km}^3}{\mathrm{sec}^2}.$$

For the Earth and the Moon, identifying the Earth with the center of gravity, we have from (8) (taking $r = 392 \cdot 10^3$ km, $T = 28$ days)

$$K^2 \, \mathrm{km/sec} = \left(\frac{2\pi \cdot 392 \cdot 10^3}{28 \cdot 86400}\right)^2 \cdot 392 \cdot 10^3 = 4 \cdot 10^5 \, \frac{\mathrm{km}^3}{\mathrm{sec}^2}.$$

For objects lying within the sphere of the Earth's pull, the mutual attraction can be found from (3)

$$F = \frac{k^2 \cdot m_1 \cdot m_2}{r^2}$$

where m_1 and m_2 are the masses in kg, r is the distance between the two objects in meters.

The gravitational constant k^2 is determined from (4). Changing over from the Earth's mass ($58{,}750 \cdot 10^{17}/9.81$ tons of mass) to the mass of 1 kg and from kilometers to meters, we find

$$k^2 = \frac{4 \cdot 10^5 \cdot 10^9 \cdot 9.81}{58750 \cdot 10^{17} \cdot 10^6} = 6.55 \cdot 10^{-10} \, \frac{\mathrm{m}^3}{\mathrm{kg} \cdot \mathrm{sec}^2}.$$

81 Thus, two objects weighing 1 kg each (the mass of each object is thus $1/9.81$ kg $\cdot$ sec^2/m) and separated by a distance of 1 m experience a mutual attraction of

$$F = 6.55 \cdot 10^{-10} \left(\frac{1}{9.81}\right)^2 = 6.81 \cdot 10^{-12} \, \mathrm{kg}.$$

Two vessels weighing 20,000 ton each attract each other at a distance of 100 m with a force of

$$\frac{(20\,000 \cdot 20\,000 \cdot 10^6) \cdot 6.81 \cdot 10^{-12}}{100^2} = 0.27 \text{ kg}.$$

Two grown men weighing 80 kg each attract each other at a distance of 2 m with a force of

$$\frac{80 \cdot 80 \cdot 6.81 \cdot 10^{-12}}{2^2} = \backsim 109 \cdot 10^{-10} \text{ kg}, = \frac{1}{100} \text{ milligram}.$$

The gravitational constant in relation to the Earth, expressed in the absolute system of units (g, cm, sec) is

$$k^2 = \frac{6.81 \cdot 10^{-12} \, (10^3)^3 \, 10^3}{(10^2)^3} \text{ g} \cdot 10^3 \text{dyne} = 0.0681 \cdot 10^{-6} = \backsim \frac{1}{15 \cdot 10^6} \text{ dyne}.$$

The two grown men in the above example thus attract each other with a force of

$$\frac{1 \cdot 80\,000^2}{15 \cdot 10^6 \cdot 200^2} = 0.0107 \text{ dyne (i. e., about } \frac{1}{100} \text{ mg)}.$$

Assuming a frictionless situation, each of the two men will move in one hour by

$$L = \frac{1}{2} \cdot at^2 = \frac{1}{2} \cdot \frac{F}{m} \cdot 3600^2 = \frac{1}{2} \cdot \frac{0.0107}{80000} \cdot 3600^2 = 0.86 \text{ cm},$$

i. e., the distance between them will decrease by 1.72 cm.

If they were both to revolve around a common center of gravity, the time of revolution could be found by setting the centrifugal force equal to the force of mutual attraction, i. e.,

$$\frac{mv^2}{\frac{r}{2}} = \frac{k^2 m^2}{r^2}$$

where $v = \frac{\pi d}{t}$, t is the unknown orbital period, and d is the separation.

82 Therefore

$$\frac{2m \cdot \pi^2 r^2}{r \, t^2} = \frac{k^2 m^2}{r^2},$$

whence

$$t = \pi \sqrt{\frac{2r^3}{k^2 m}}.$$

* One dyne is the force which imparts an acceleration of 1 cm/sec^2 to a mass of 1 g. The weight of 1 g on the Earth's surface, where the acceleration is 9.81 m/sec^2, corresponds to a force of 981 dyne or approximately 10^3 dyne.

Inserting the numerical values

$$r = 200 \text{ cm};$$
$$k^2 = \frac{1}{15.10^6} \text{ dyne};$$
$$m = 80{,}000 \text{ g}$$

we have

$$t = 3.14\sqrt{\frac{2.200^3\, 15.10^6}{80000}} = 172{,}000 \text{ sec} = 47.7 \text{ hrs.}$$

If these two men were to fall one toward the other in vacuum, the time of fall would be

$$t = \frac{47.7/2}{5.6} = \backsim 4.2 \text{ hrs.}$$

One cubic meter of water at 4°C on the Earth's surface weighs 1,000 kg or 10^6 g. When the Sun or the Moon is the zenith, the attraction reduces the weight of this volume of water by the following amounts:

	Sun in zenith	Moon in zenith
In perihelion	0.056204 g	0.138924
Mean distance	0.051547 g	0.117030
In aphelion	0.049142 g	0.099875

i. e., on the average, the Moon reduces the weight of 1 m^3 of water by 1/10 g and the Sun by 1/20 g.

Corollaries of Newton's law. Since the acceleration is proportional to the force of attraction, and the latter in its turn is inversely proportional to the square of the distance, the gravitational acceleration will diminish as the square of the distance from the Earth's center, i. e.,

$$g = g_0 \frac{r^2}{(r+s)^2} \text{ m/sec}^2 \qquad (9)$$

where r is the Earth's radius in m;
s is the altitude above sea level;
g_0 is the gravitational acceleration at sea level.

83 TABLE 13. Gravitational acceleration

Geographical latitude in degrees	Altitude above sea level in meters					
	0	100	500	1,000	2,000	3,000
0°	9.7801	9.7797	9.7785	9.7769	9.7739	9.7710
20	9.7860	9.7857	9.7845	9.7830	9.7799	9.7768
40	9.8011	9.80085	9.7996	9.7981	9.7950	9.7919
45	9.8055	9.8052	9.8039	9.8024	9.7993	9.7962
50	9.8099	9.8096	9.8083	9.8068	9.8037	9.8007
60	9.8182	9.81785	9.8167	9.8151	9.8121	9.8090
70	9.8250	9.8246	9.8234	9.8219	9.8188	9.8157
80	9.82935	9.8290	9.8278	9.8263	9.8232	9.8201
90	9.8310	9.8306	9.8293	9.8277	9.8248	9.8215

The following formula expresses the gravitational acceleration g at various latitudes and for various altitudes above sea level:

$$g = 9.80549 \cdot (1 - 0.00259 \cdot \cos 2a) \cdot (1 - 0.0^{(6)}313959 \cdot h).$$

The gravitational acceleration at sea level can be expressed by Helmert's formula

$$g = 978.030\,(1 + 0.005302 \sin^2 \lambda - 0.000007 \sin^2 2)\ \frac{\text{cm}}{\text{sec}^2}$$

where λ is the local latitude.

From this formula we have

g = 978.030 cm/sec^2 at the equator ($\lambda = 0$);
g = 980.616 " at the latitude $\lambda = 45°$;
g = 983.215 " at the pole ($\lambda = 90°$).

(84)

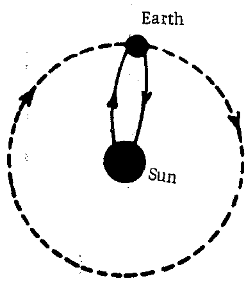


FIGURE 69.

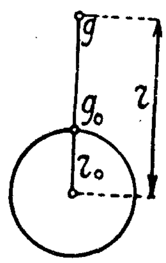


FIGURE 70.

Let us determine the gravitational acceleration of a planet whose density is equal to the density of the Earth, but whose radius is different. We use the following notation:

	For the Earth	For the planet
radius	r_0 (Figure 70)	r
gravitational acceleration	g_0	g
mass	m_0	m

84 then

$$\frac{g}{g_0} = \frac{\frac{m}{r^2}}{\frac{m_0}{r_0^2}}.$$

The mass is proportional to the cube of the radius, so that

$$\frac{g}{g_0} = \frac{r^3 \cdot r_0^2}{r_0^3 \cdot r^2} \text{ or } g = g_0 \cdot \frac{r}{r_0} \qquad (10)$$

A nomogram for gravitational accelerations

The gravitational acceleration is expressed by the equality $g = \frac{G.M}{R^2}$ where M is the mass, R is the distance from the center of attraction, G is the gravitational constant (in CGS units, $6.68 \cdot 10^{-8}$). Figure 71 shows a nomogram for the computation of the gravitational acceleration g of any planet and at any distance from it.

The right-hand scale gives the values of g on the surface of the major planets, the middle scale gives the distances R, and the left-hand scale gives the mass.

(85)

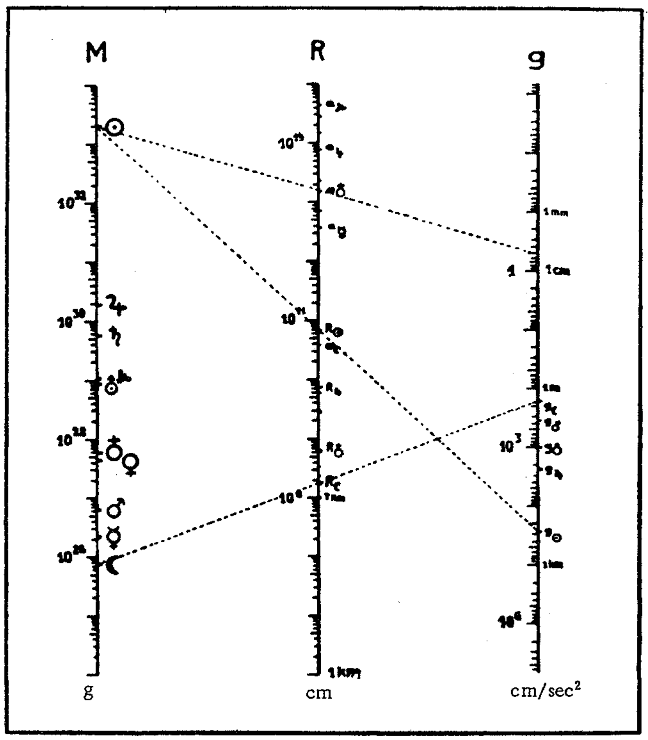


FIGURE 71. A nomogram for computing the gravitational acceleration of various planets

The velocity of fall of objects on various planets depends on the gravitational acceleration at the surface of the corresponding planet. The appropriate data are listed in Table 2 and summarized graphically in Figure 72. An object falling on the Earth will cover a distance of 4.9 m during the first sec, on the Moon a distance of 0.81 m during the first sec, and on the Sun 134.62 m during the first sec. The weight of the object changes accordingly. An object weighing one kg on the Earth will weigh 166 g on the Moon and 28.04 kg on the Sun. The above computations were carried out ignoring the atmosphere. Note that the faster the axial rotation of the planet, the smaller the gravitational acceleration.

(86)

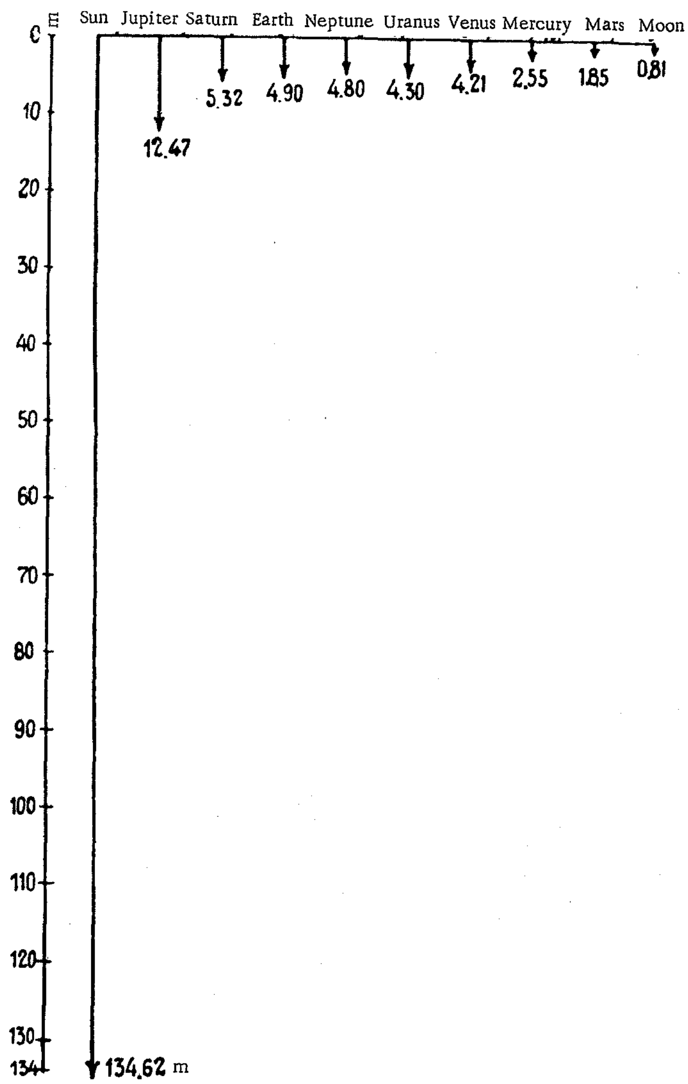


FIGURE 72. Possible path traversed in one second by a body falling on various planets in a vacuum

85
(87)

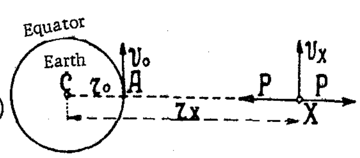


FIGURE 73.

Problem. Find at what distance from the Earth's center in the equatorial plane the weight of a body is balanced by the centrifugal force (Figure 73).

Solution. The distance r of the unknown point X from the Earth's center C is determined from the condition that the centrifugal force F at this point is equal to the weight of the body P.

Let the mass of the body be m, the Earth's rotational velocity at the equator $V_0 = 465$ m/sec, the rotational velocity of the point X, V_x, the gravitational acceleration at the equator $g_0 = 9.78$ m/sec^2, the acceleration at altitude r_x, g_x.

We have

$$F = \frac{m \cdot V_x^2}{r_x}; \quad P = mg_0 \cdot \frac{r_0^2}{r_x^2}.$$

Since $F = P$, we find

$$\frac{mV_x^2}{r_x} = mg_0 \cdot \frac{r_0^2}{r_x^2}.$$

But $V_x = V_0 \frac{r_x}{r_0}$; therefore, inserting this expression in the previous equality and cancelling, we find

$$\frac{m \cdot V_0^2 \cdot r_x}{r_0^2} = mg_0 \frac{r_0^2}{r_x^2}; \quad \text{and } r_x^3 = \frac{g_0}{V_0^2} r_0^4$$

87 Inserting the numerical values of

$$g_0 \cdot V_0 \quad \text{and} \quad r_0 = 6{,}371{,}000 \text{ m},$$

we find

$$r_x = 42{,}125 \text{ km} = \backsim 6.5\ r_0.$$

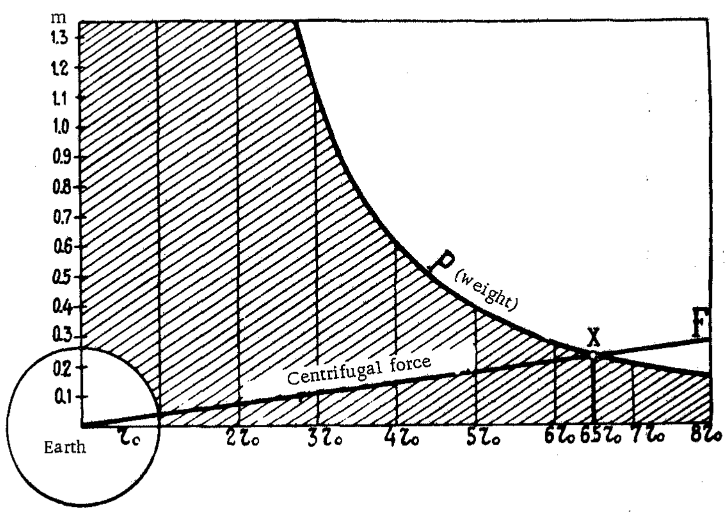


FIGURE 74.

r_x	P	F	r_x	P	F
r_0	9.78 *m*	0.034 *m*	$5r_0$	0.391 *m*	0.170 *m*
$2r_0$	2.445 *m*	0.068 *m*	$6r_0$	0.272 *m*	0.204 *m*
$3r_0$	1.087 *m*	0.102 *m*	$7r_0$	0.200 *m*	0.238 *m*
$4r_0$	0.611 *m*	0.136 *m*	$8r_0$	0.153 *m*	0.271 *m*

Figure 74 shows the functions P and F in graphical form. The ordinates of the points of the hyperbola (P) and the straight line (F) are also listed in the table. The weight is balanced by the centrifugal force at the point X with $r_x = 6.6\,r_0$.*

38 THE WORK OF GRAVITATION

If a spacecraft of mass m moves through space along the path $0-1$ in the gravitational field of planet S (Figure 75), the work of gravitation from 0 to 1 is equal to the integral over the gravitational force $\frac{k^2 Mm}{r^2}$ multiplied by the increment of the orbital radius dr, i. e.,

$$R = -\int_{r_1}^{r} k^2 \frac{Mm}{r^2}\,dr = k^2 Mm\left(\frac{1}{r} - \frac{1}{r_1}\right) \qquad (11)$$

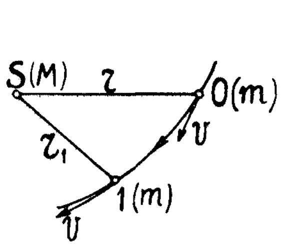


FIGURE 75.

where M is the mass of the planet;
k^2 the gravitational constant;
r and r_1 the corresponding orbital radii.

This work of gravitation is equal to the change in the kinetic energy of the spacecraft, i. e.,

$$k^2 Mm\left(\frac{1}{r} - \frac{1}{r_1}\right) = \frac{mV_1^2}{2} - \frac{mV^2}{2}, \qquad (12)$$

where V and V_1 are its velocities at points 0 and 1.

Example 1. Find the work required in order to lift an object weighing 1 kg from the Earth's surface (r = 6,371 km = $6.371 \cdot 10^6$ cm) to a certain height $r_1 > r$.

Changing over from kilometers to meters and using

$$m = \frac{1}{9.81} = \infty \frac{1}{10},$$

we obtain from (11)

$$R = 4\ 10^5 \cdot 10^8 . M . \frac{1}{10}\left(\frac{1}{r} - \frac{1}{r_1}\right),$$

but $M = 1$, so that

$$R = 4 \cdot 10^{13}\left(\frac{1}{r} - \frac{1}{r_1}\right) \text{kg} \cdot \text{m}$$

For $r_1 = 60r$, we thus have

$$R = \frac{4\cdot 10^{13}}{6.37\cdot 10^6} \cdot \frac{59}{60} = \infty\, 6.3 \cdot 10^6 \,\text{kg}\cdot\text{m}.$$

To remove an object weighing 1 kg to infinity, we have to do work against gravitation of

$$R = \frac{4\cdot 10^{13}}{6.4\cdot 10^6} = 6.371 \cdot 10^6 \text{ kg}\cdot\text{m}.$$

* Note that in the ancient Indian astronomical annals, the radius of the "true Earth" was taken equal to $6.5\,r_0 \approx 40{,}000$ km. See G. W. Syrya and M. Valier "Okkulte Weltalls Lehre," Munchen, p.89. 1922.

89 *Alternative method of solution.* If the object weighs 1 kg, the force of attraction on this object is given by

$$f = k^2 \frac{Mm}{r^2} = 1.$$

For

$$r = 6371 = 6.371 \cdot 10^6 \text{ and } m = \frac{1}{9.8} = \backsim 0.1$$

we have

$$k^2 \cdot M \cdot 0.1 = 1.6.371^2 \cdot 10^{12},$$

and this constant is designated by A.

On moving to infinity, the work done is

$$R = \int_{r_0}^{r} = A\left(\frac{1}{r} - \frac{1}{r\infty}\right) = \frac{A}{r} = 6.371 \cdot 10^6 \text{ kg} \cdot \text{m}.$$

i. e., the same as before.

Third method of solution. If and object of mass m is lifted from a height r above the Earth's center, where the gravitational acceleration was g_0 and the velocity V, to a height r_1, corresponding to g_1 and V_1, we have

$$g_1 = g_0 \cdot \frac{r^2}{r_1^2}.$$

The work done against the gravitational forces is thus

$$R = \int_{r}^{r_1} m \cdot g_0 \frac{r^2}{r_1^2} dr = m \cdot g_0 r^2 \left(\frac{1}{r} - \frac{1}{r_1}\right). \quad (13)$$

If the weight of the object is $m \cdot g_0 = 1$ kg and $r = 6.378 \cdot 10^6$ m, the work done to move the object to infinity is

$$R = 1 \cdot (6.378 \cdot 10^6)^2 \left(\frac{1}{6.378 . 10^6} - \frac{1}{\infty}\right) = 6.378 \cdot 10^6 \text{ kg} \cdot \text{m}.$$

Example 2. Find the work required to eject an object [on Earth] weighing 1 kg from the surface of the Moon. The weight of the object on the Moon is approximately 0.17 kg. The radius of the Moon is $r = \backsim 1{,}740$ km $= 1.74 \cdot 10^6$ m. The force of attraction exerted by the Moon on an object weighing 1 kg [on Earth], whose mass is thus 0.1 kg, is given by

$$0.17 = \frac{k^2 \cdot M \cdot 0.1}{(1.74 \cdot 10^6)^2} = \frac{A_1}{(1.74 \cdot 10^6)^2}, \text{ whence } A_1 = 0.52 \cdot 10^{12}.$$

The work done against the lunar gravitation when an object weighing 1 kg is flown from the Earth to the Moon is found as follows: assuming that the distance of the Moon from the Earth is $60r$, where r is the Earth's radius, we have

$$R=A_1\left(\frac{1}{r}-\frac{1}{60\,r}\right).$$

90 The second term in parenthesis is very small compared with the first term, and the work of lunar attraction is thus

$$\frac{A_1}{r}=\frac{0.52\cdot 10^{12}}{6.74\cdot 10^{6}}=0.3\cdot 10^{6}.$$

The work of gravitation on the Earth is $6.3\cdot 10^6$, i.e., the work of gravitation on the Moon is almost 1/21th of the corresponding figure for the Earth. The flight from the Moon to the Earth is therefore much easier.

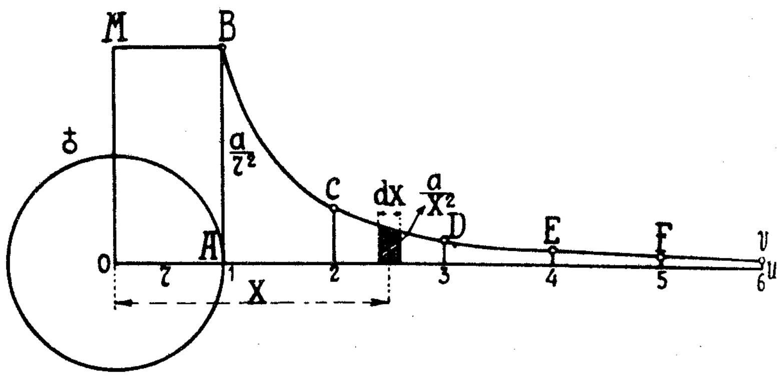


FIGURE 76

Let us plot the curve showing how the weight of an object varies with distance from the Earth. In Figure 76 the Earth is represented by a circle of radius r. We draw the abscissa axis OU and erect the ordinate axis perpendicular to it, from the end of the radius r. We then cut off a segment AB equal to the weight of the object on an arbitrary scale along the ordinate axis. We express this weight by the fraction $\frac{a}{r^2}$, where a is a number which depends on the Earth's mass and the mass of the object, and r is the radius of the Earth. Then at a distance equal to two Earth radii, the weight of the object will be $\frac{a}{(2r)^2}$, at a distance equal to three Earth radii $\frac{a}{(3r)^2}$, and at a distance x it will be $\frac{a}{x^2}$. Plotting these values as the ordinates at the corresponding points, we obtain the curve $BCDEFV\ldots$, which asymptotically approaches the axis AU. We will now prove that the area between the axis AU, the vertical segment AB and the curve BV (when extended to infinity) is equal to the area of the rectangle $OABM$.

Consider an element of this area (diagonally hatched in the figure) of width dx at a distance x from the center O. Its area is equal to

$$dp=\frac{a}{x^2}\cdot dx.$$

91 Integrating from r to ∞, we obtain the total area under the curve

$$P=\int_r^{\infty}\frac{a\,dx}{x^2}=a\left[-\frac{1}{x}+c\right]_r^{\infty}=\frac{a}{r}=OA\cdot AB=r\cdot\frac{a}{r^2}.$$

Q. E. D.

This area (***OABM***) gives the work done against the gravitation in order to move the object beyond the sphere of the Earth's attraction. This escape work is equal to the radius of the Earth multiplied by the weight of the object. For an object weighing 1 kg on the Earth's surface, this work (for r = 6,371 km) is equal to 6,371,000 kg · m.

If the gravitational acceleration at the Earth's surface is taken as unity, the gravitational acceleration at the surface of other planets will vary with the ratio of the planetary mass and the planetary radius to those of the Earth. For the Moon, whose mass is 0.01228 of the Earth's mass and the radius is 0.273 of the Earth's radius, the gravitational acceleration is $\frac{1\cdot 0.01228}{0.273^2} = \sim 0.17$.

For the asteroid Pallas, $\frac{1\cdot 0.038^2}{0.038^2} = 0.038$.

For Venus, $\frac{1\cdot 0.817}{0.955^2} = 0.895 = \sim 0.9$.

The data on the masses and radii of various planets listed in Tables 2 and 5 of the previous chapter were applied to compute the gravitational acceleration of various planets. Figures 77 and 78 were constructed, similar to Figure 76, showing the variation of the gravitational attraction of these planets with the distance (the gravitational force at the surface of the Earth was taken as unity). The same scale was used on the ordinate axes in Figures 77 and 78, but the scale on the abscissa axis in Figure 78 is 1/10 of the scale on Figure 77. For comparison, the curve of terrestrial
92 gravitation is shown in each figure. Figure 77 shows the curves for the Earth (1.00), Venus (0.9), Mars (0.38), the Moon (0.17), and Pallas (0.038). Figure 78 gives the curves for Jupiter (2.54), Saturn (1.02), Uranus (1.0), Earth (1.0), and Neptune (0.89).

(91)

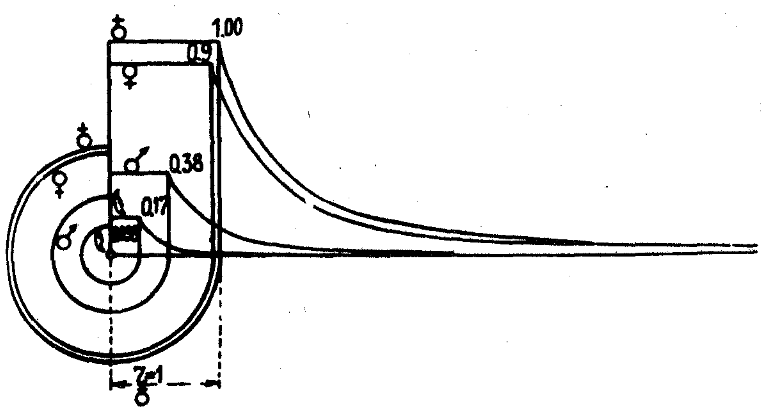


FIGURE 77.

(93)

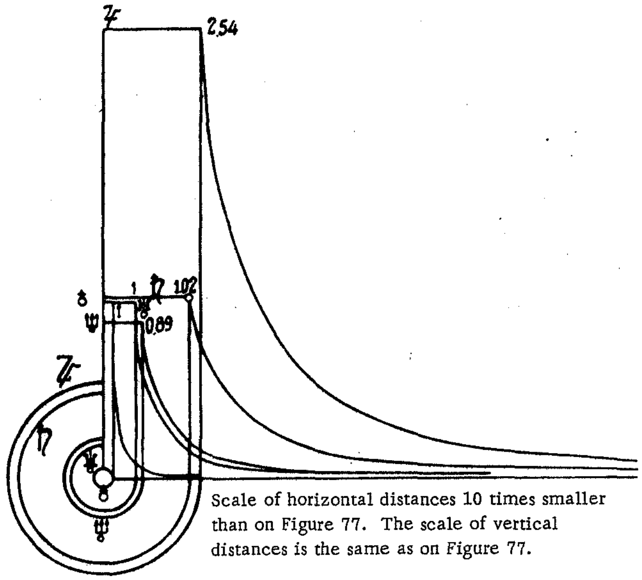


FIGURE 78. Gravitational pull of the planets as a function of distance

Comparison of the areas of similar triangles for different planets gives an indication of the differences in the work against gravitation on different planets. We thus see from what planets it is relatively easy to launch a given spacecraft, and from what planets the launching is more difficult.

Table 14 summarizes the results of this comparison.

We see from the table that the launching of a spacecraft from Pallas, Moon, Mercury, Mars, Venus requires less energy than the launching of the same craft from the Earth, whereas the launching from the other planets requires more energy. For example, the work to be done against the gravitation of Jupiter is almost 28 times higher, and the same work of the Sun is 3,058 times higher.

TABLE 14.

Planet	Radius	Gravitational acceleration	Work against gravitation
	(in units of the corresponding terrestrial quantities)		
Earth	1	1	1
Pallas	0.038	0.038	0.0014
Moon	0.273	0.166	0.045
Mercury	0.38	0.386	0.147
Mars	0.532	0.381	0.203
Venus	0.955	0.897	0.857
Uranus	3.81	1.005	3.829
Neptune	4.39	0.894	3.925
Saturn	9.64	1.024	9.871
Jupiter	11.19	2.542	23.44
Sun	109.05	28.04	3,058.00

When launching a spacecraft from one planet to another, the gravitational attraction of one planet is somewhat reduced by that of its counterpart (given the relatively short distances between planets). There is a point between any pair of planets where the gravitational pull of the two planets is balanced, and if an object reaching this point were to stop, it would not fall to any of the two competing worlds. Figure 79 shows as an example two planets of equal density having the radii r and $\frac{r}{2}$; the distance between their centers is $5r$. If the gravitational pull on the surface of the
93 left planet is $\frac{1}{r^2}$ the gravitational pull on the surface of the right planet is $\frac{1}{8\left(\frac{r}{2}\right)^2}=\frac{1}{2r^2}$. The gravitational pulls are balanced at some point M_1 where

$$\frac{1}{x^2}=\frac{1}{8(5r-x)^2};\text{ where } x=3.7\,r.$$

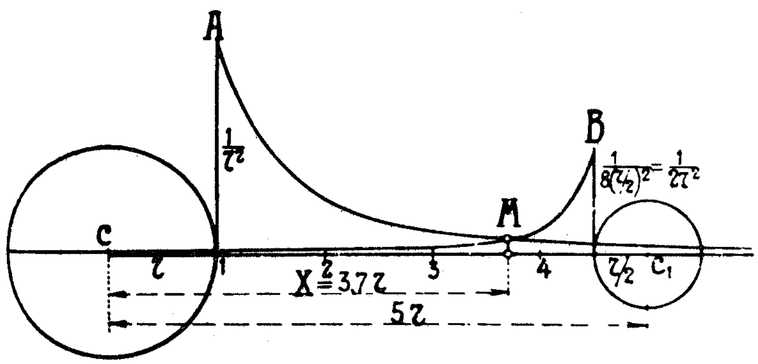


FIGURE 79. Gravitational pull of planets as a function of distance

The second solution of this equation gives a point to the right of c, where the gravitational forces of the two planets are again balanced, but they have the same sign and are thus of no interest for our purpose. Besides the point M with the coordinate x (Figure 79) where the gravitational pull of the two planets is balanced, there is a whole locus of points in space which have the same neutral property.

94

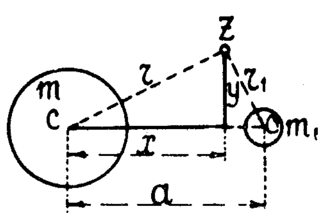


FIGURE 80.

We partition the space by a plane through the centers of the two planets C and C_1 (Figure 80) and consider the solution of the problem in this plane, assuming spherical planets.

Let the object lie at the neutral point Z where the gravitational pull of the planet C is balanced by that of C_1. Let the coordinates of the point Z be x and y, and the corresponding distances to the two planets r and r_1, respectively. Writing m and m_1 for the masses of the two planets, we have

$$\frac{m}{r^2}=\frac{m_1}{r_1^2}. \qquad (1)$$

But

$$r^2=x^2+y^2;\ r_1=y^2+(a-x)^2,$$

where a is the distance between the centers of the planets. Inserting r and r_1 in (1), we find

$$\frac{m}{x^2+y^2}=\frac{m_1}{y^2+(a-x)^2},$$

whence

$$x^2+y^2-\frac{2ma}{m-m_1}x+\frac{ma^2}{m-m_1}=0.$$

This is the equation of an ellipse. The sought surface is thus an ellipsoid of revolution.

THE LAUNCHING VELOCITIES FROM PLANETS INTO OUTER SPACE AND THE FLIGHT TRAJECTORIES

Let us find the horizontal launching velocities required on different planets in order to overcome the gravitational attraction of the planet and escape into interplanetary space.

The planets are assumed to be without atmosphere, so that the gravitational attraction is the only resistance to the outward motion of the body.

95

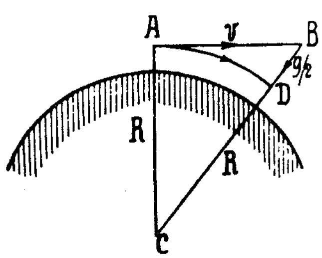


FIGURE 81.

Figure 81 shows a section through a planet with an object launched from a point A on its surface with a horizontal velocity $V=AB$ meters/sec. Let the radius of the planet be $AC=R$. Without planetary attraction, the body would reach the point B in 1 sec, but because of the gravitational pull it draws closer to the center C of the planet by a distance $BD=\frac{g}{2}$, i. e., by an amount equal to half the gravitational acceleration.

The object will continue circling the planet in the direction of the arc AD, without falling, if (from the triangle ABC)

$$AB^2=BC^2-AC^2$$

or

$$V^2=\left(R+\frac{g}{2}\right)^2-R^2=gR+\frac{g^2}{4}.$$

Neglecting $\frac{g^2}{4}$ in comparison with gR we find

$$V=\sqrt{gR} \qquad (13)$$

As long as the body moves with a velocity V described by (1), it will describe a circular velocity around the planet, as its satellite. If V is increased, the orbit will develop into an ellipse, which becomes progressively more eccentric as V increases. Finally, for velocities equal to $V\sqrt{2}$, the body will move in a parabolic orbit, escaping from the planet (Figures 82 and 83).

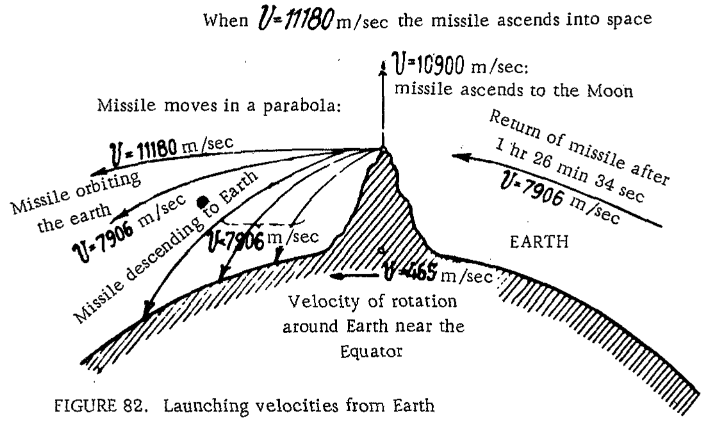


FIGURE 82. Launching velocities from Earth

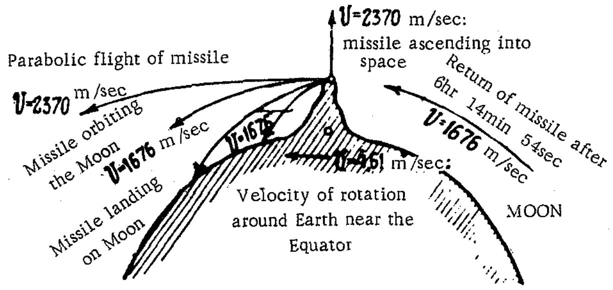


FIGURE 83. Launching velocities from Moon

97 Table 15 lists the velocities V and $V\sqrt{2}$ for the various planets of the solar system. For example, an object launched from the Earth with a velocity of 7,906 m/sec will move in a circular orbit around the Earth (Figure 84); for launching velocities between 7,906 and 11,180 m/sec the object will move in elliptical orbit, and for $V = 11{,}180$ it will escape from the Earth describing a parabolic orbit. The same conclusion is reached using equations (12) and (13), i.e., setting the work against gravitation equal to the change in the kinetic energy:

$$\frac{m(V^2-V_1^2)}{2} = mg_0 r^2\left(\frac{1}{r}-\frac{1}{r_1}\right) \qquad (12b).$$

Assuming that the body stops completely ($V_1 = 0$) only at infinity ($r_1 = \infty$), we find

$$V = \sqrt{2g_0 \cdot r} = \sqrt{2\cdot 9.80665\cdot 6378000} = 11{,}180 \text{ m/sec}.$$

TABLE 15. Launching velocities for various planets

(96)

Planet	Radius R, km	Gravitational acceleration g m/sec^2	gR, m^2/sec^2	Circular velocity $V=\sqrt{2gR}$ /sec	Parabolic velocity $V_1=\sqrt{2gR}$ /sec
Sun	695445	269	187074705000	432521	611628
Mercury	2420	5.1	12342000	3573	5052
Venus	6087	8.42	51252000	7160	10126
Earth	6371	9.81	62500000	7906	11180
Moon	1736	1.62	2812000	1676	2370
Mars	3391	3.69	9122000	3620	5119
Atlanta	15	0.023*	345	19	27
Pallas	243	0.37*	90000	300	424
Ceres	402	0.62*	249240	500	707
Jupiter	71364	24.94	1779818000	42188	59662
Saturn	61513	10.64	654498000	25583	36179
Uranus	24292	8.60	208911000	14453	20439
Neptune	28017	9.60	268963000	16402	23196

* For planetoids $g_n = 9.81\ R_n/R_3$, e.g., for Pallas $g = 9.81 \cdot 243/1371 = 0.37$ (its density is assumed to be equal to that of the Earth).

When moving in a circular orbit around the Earth, the orbit completes one circuit in 1 hr 26 min 34 sec. In order to launch an object from the Earth to the Moon, a velocity smaller than $V\sqrt{2}$ is needed: this velocity is 10,900 m/sec, since the kinetic energy of the missile only has to carry it as far as the surface where the gravitational pull of the Earth is balanced by that of the Moon. This neutral surface extends at a distance of 345,963 km from the Earth and 8,337 km from the Moon (Figure 85). Its position is determined as follows. Let the distance from the Earth's center be x the mass of the Earth M the mass of the Moon M_1 the mass of the missile m, the universal gravitational constant k. By Newton's law, we then have

$$k\frac{Mm}{x^2}=k\frac{M_1 m}{(384300-x)^2},$$

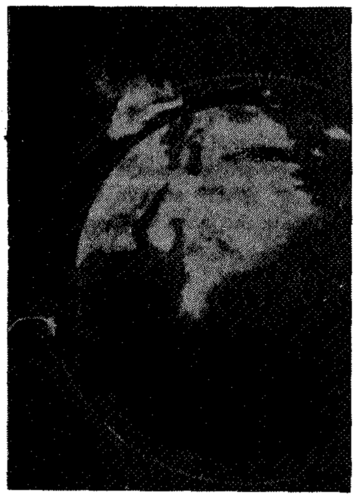


FIGURE 84. A missile in a circular orbit

98 where 384,300 km is the mean distance from the Earth to the Moon. But $M_1 = 0.01228\ M$; and we find from this equation $x = 345{,}963$ km.

A missile will describe a circular orbit around the Moon if it is launched from the lunar surface with a velocity of 1,676 m/sec; it will complete one circuit around the Moon in 6 hr 14 min 54 sec. If launched with a velocity of 2,370 m/sec, the missile will escape from the Moon and become a satellite of the Earth. If a lower launching velocity is used, the missile will fall on the Earth (Figure 83).

The trajectories of a stone thrown with different velocities were described by Newton in his "Principia Mathematica."

Similar computations carried out for the Earth moving as an object in its orbit around the Sun give the following orbits for different velocities (the Earth actually moves in an elliptical orbit, with $V = 29.45$ km/sec):

V, km/sec	Orbit
29.45	ellipse
27.7	circle
< 27.7	ellipse approaching the Sun
42	parabola
> 42	hyperbola

(97)

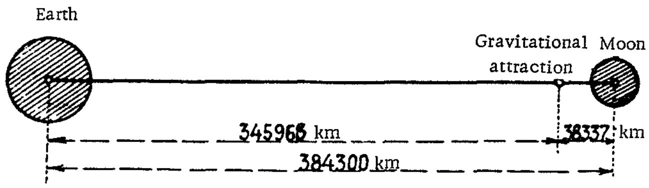


FIGURE 85

The trajectory of a rocket flying from the Earth to another planet can be divided into 3 parts: 1) powered flight, when the rocket is propelled by its engines until the parabolic velocity is attained, 2) free flight along the arc of an ellipse (Keplerian curve), until the rocket approaches the sphere of attraction of the target planet, 3) landing with deceleration achieved by retro engines.

A rocket launched from the Earth with a velocity sufficient for overcoming its gravitational attraction will describe an orbit around the Earth as its primary. Since the Earth moves around the Sun, the orbit of the rocket and the rocket itself will move together with the Earth in its orbit around the Sun. For the rocket to be able to escape from the Earth in order to approach the Sun or move farther away from it, its velocity should be greater than the orbital velocity of the Earth, approximately equal to 29.45 km/sec.

If the Earth were an isolated planet, stationary in infinite space, the launched missile, free from any perturbations, would describe a regular ellipse and after a certain time return to the point of origin. The orbital period would be long for sufficiently high velocities, and it may even reach
99 a few million years. However, upon its return to the Earth, the rocket would move with the original launching velocity.

Suppose that a rocket is launched from the Earth in a direction against the orbital motion of the Earth around the Sun (Figure 86). If the velocity of the rocket relative to the Earth drops to zero at a certain altitude, it nevertheless continues moving with a velocity of 29 km/sec relative to the Sun together with the Earth. If it persists in its original motion, its velocity relative to the Sun is smaller and it will describe a trajectory bringing it closer to the Sun. Appropriately adjusting the velocities, we can direct this trajectory so that it passes close to one of the inferior planets, Mercury, for example. At an appropriate time, when the rocket is closest to this planet, its engines are fired in order to land or to describe a closed orbit around the planet. The corresponding situation is shown in Figure 86 (trajectory acfg). For certain velocities, the rocket may even fall on the Sun. If the rocket is expected to fly to one of the superior planets, it should be launched in the direction of the Earth's orbital motion, so that its velocity relative to the Sun exceeds 29 km/sec. It will then describe a Keplerian curve outside the Earth's orbit and, as before, it may be directed to Mars and made to circle the planet or land on it. This case is shown in Figure 86 by curve abcd. The rocket will completely escape from the solar system if it leaves the Earth's orbit with the velocity $V_0 = 29.45 \cdot \sqrt{2}$, where 29.45 km/sec is the orbital velocity of the Earth (assuming a circular path around the Sun). We thus find for this escape velocity $V_0 = \sim 42$ km/sec. For velocities between 29.45 km/sec and 42 km/sec the rocket will move in ellipses which may touch the orbits of any of the superior planets. Figure 87 shows one of such ellipses, touching the orbit of Mars.

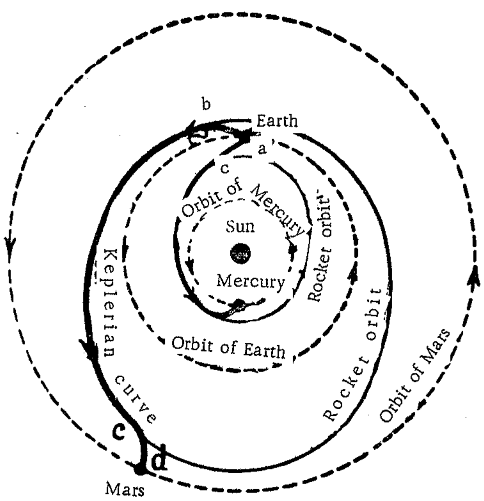


FIGURE 86. Flight of a rocket to Mercury and Mars

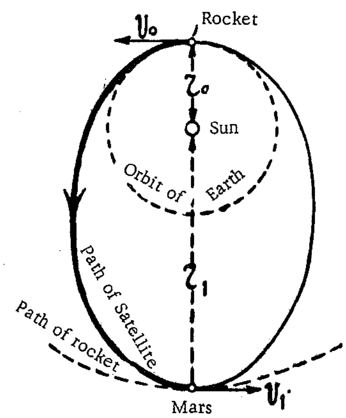


FIGURE 87. Trajectory of a rocket to Mars

100 An object launched away from the Sun will penetrate deep into interstellar space, provided that it is not captured by one of the planets (a very unlikely proposition). On its way back, however, it is attracted by the combined gravitational pull of the solar system, and not by the Earth alone; therefore, it would circle once around the Sun, like a comet, and only then return to the point of origin in the Earth's orbit. The same situation will recur many times, until the missile again encounters the Earth and its flight is terminated. The velocity of encounter with the Earth depends on the gravitational pull of the Sun, combined with the resultant velocity, i. e., not only the circular velocity of the Earth in its annual orbit ($V = 30$ km/sec) but also with the elliptical velocity, the maximum value of which is $30\sqrt{2} = 42.4$ km/sec. If at the time of the encounter the Earth and the rocket are on collision courses, the velocity of encounter would be $42.4 + 30 = 72.4$ km/sec ± the velocity of axial rotation of the Earth (0.465 km/sec).

The temperature of spacecraft in outer space

Esnault-Peltrie carried out computations for a rocket covered on one side with copper oxide (emissivity $k = 0.85$) and on the other side with polished aluminum ($k = 0.13$). These computations give the following temperatures T for the hot (sunlit) and the cold (shadowed) sides of the rocket at the distances corresponding to those of various planets from the Sun.

Near the Earth	$T = -89.6$°C;	$T = +20.4$°C
" Venus	$T = -56.9$°C;	$T = +72.5$°C
" Mars	$T = -124.3$°C;	$T = -35.2$°C
" Mercury	$T = +20.5$°C;	$T = +136$° C

For comparison, we give some data on the temperature and the atmospheres of certain planets.

Moon: dark side, −173°C; illuminated side, +77°C (and even 127°C).

Venus: outer cloud layer, +60°C; surface temperature lower.

Mars: mean surface temperature, −30°C; at the equator +20°C, at the poles, −60°C. Atmosphere, 200 km high. Oxygen content, 3% of its content in the Earth's atmosphere.

Jupiter and Saturn both have thick, dense atmospheres.

101 BALLISTIC PROBLEMS (CRANZ)

Consider the flight of a missile around the Earth, which is assumed to be stationary.

Let the Earth's center M (Figure 88) be the origin of a polar system of coordinates. Then every point P of the flight trajectory has the coordinates $r = MP$ (the radius-vector) and $\alpha = \angle OMP$ (the polar angle). The coordinates of the launching point A are assumed to be known: $r_0 = 6{,}370{,}000$ m and the angle φ.

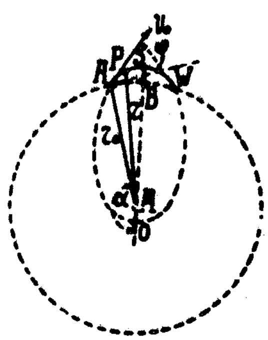


FIGURE 88.

FIGURE 89.

For the point P, Newton's law gives the gravitational acceleration $g \cdot \frac{r_0^2}{r^2}$ or briefly ξ. The law of real velocities gives for the entire trajectory

$$r^2 \cdot \frac{d\alpha}{dt} = c,$$

where the constant c is determined from the initial conditions (the point A), when $r\,d\alpha = ds \cdot \cos\varphi$ (ds is an element of arc of the trajectory) (Figure 89) and dr/dt = v_0. Therefore

$$r^2 \frac{d\alpha}{dt} = c = r_0 v \cdot \cos\varphi. \qquad (1)$$

For the motion of the missile in its trajectory, we have

$$\frac{dv}{dt} = -\frac{\mu}{r^2} \cdot \frac{dr}{ds} \quad \text{or} \quad v \cdot \frac{dv}{dr} = -\frac{\mu}{r^2}.$$

102 Integration from A to P gives

$$v^2 - v_0^2 = -2\mu \int_{r_0}^{r} r^{-2} . dr = 2\mu \left(\frac{1}{r} - \frac{1}{r_0}\right); \quad \text{or} \quad v^2 = q + \frac{2\mu}{r}, \tag{2}$$

$$q = v_0^2 - \frac{2\mu}{r_0}.$$

Since

$$v^2 = \left(\frac{ds}{dt}\right)^2 = \left(\frac{dr}{dt}\right)^2 + r^2 \left(\frac{d\alpha}{dt}\right)^2 \quad \text{and} \quad \frac{dr}{dt} = \frac{dr}{d} \cdot \frac{d\alpha}{dt},$$

or, using (1)

$$\frac{dr}{dt} = \frac{dr}{d\alpha} \cdot \frac{c}{r^2},$$

we write equation (2) in the form

$$q + \frac{2\mu}{r} = \left(\frac{dr}{d\alpha}\right)^2 \cdot \frac{c^2}{r^4} + \frac{c^2}{r^2},$$

which gives

$$d\alpha = \frac{\frac{c}{r^2} \cdot dr}{\sqrt{q + \frac{2\mu}{r} - \frac{c^2}{r^2}}} = \frac{d\left(\frac{\frac{c}{r} - \frac{\mu}{c}}{\sqrt{q + \frac{\mu^2}{c^2}}}\right)}{\sqrt{1 - \left(\frac{\frac{c}{r} - \frac{\mu}{c}}{\sqrt{q + \frac{\mu^2}{c^2}}}\right)^2}}.$$

This is the differential equation of the missile trajectory with two unknowns r and α.

Integration of this equation gives

$$\alpha - \gamma = \arccos \frac{\frac{c}{r} - \frac{\mu}{c}}{\sqrt{q + \frac{\mu^2}{c^2}}}$$

or

$$r = \frac{p}{1 + \varepsilon . \cos(\alpha - \gamma)}. \tag{3}$$

Here γ is the integration constant and

$$p = \frac{c^2}{\mu} \quad \text{and} \quad \varepsilon = \sqrt{1 + \frac{q . c^2}{\mu^2}}.$$

Equation (3) shows that the trajectory of a missile is a conic section. To find the constant, we recall that

$$r=\frac{p}{1+\varepsilon.\cos a}$$

is the equation of a conic section in polar coordinates, with the parameter (Figure 90)

$$p=\frac{b^2}{a}=\frac{a^2-d^2}{a}=a-\varepsilon.d=a-\varepsilon^2.a=a(1-\varepsilon^2).$$

103 Here a and b are semimajor and semiminor axes (the focus lies on a), d is the linear eccentricity, i.e., the distance of the focus from the center, and $\varepsilon=\frac{d}{a}$ is the so-called numerical eccentricity. The focus M coincides with the pole of the coordinate system and the polar angle a is reckoned from the apex 0 of the curve which is closest to M on the semimajor axis. For $\epsilon < 1$, this equation gives an ellipse, for $\epsilon = 0$ a circle, for $\epsilon = 1$ a parabola, and for $\epsilon > 1$ a hyperbola.

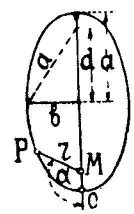


FIGURE 90.

If we take $\gamma = 0$ in this equation, this means that the polar axis OM joins the perihelion O of the conic section (i.e., the end of the semimajor axis closest to the Earth) with the Earth's center M. We thus have

$$r=\frac{p}{1+\varepsilon\cos a}, \tag{4}$$

$$v^2=v_0^2-\frac{2\mu}{r_0}+\frac{2\mu}{r}, \tag{5}$$

where

$$p=\frac{c^2}{\mu} \text{ and } \varepsilon=\sqrt{1+\frac{qc^2}{\mu^2}};$$

$$q=v_0^2-\frac{2\mu}{r_0},\quad \mu=gr_0^2,\quad c=r_0v_0\cos\varphi,\quad r_0=6\,370\,300 \text{ m}.$$

Since $r_0, \varphi, v_0, c, \mu, q, \varepsilon, p$ are known, from equation (4) for any a we can find the distance r of the missile from the Earth's center, and using equation (5) we can compute the velocity v for the corresponding point (r, a) of the trajectory. The time of flight is found by integrating the equation

$$dt=\frac{r^2.da}{c}.$$

The trajectory is an ellipse if $\epsilon < 1$, i.e., if

$$1+\frac{c^2}{\mu^2}\left(v_0^2-\frac{2\mu}{r_0}\right)<1$$

or if

$$v_0<\sqrt{\frac{2\mu}{r_0}};$$

but

$$\sqrt{\frac{2\mu}{r_0}} = \sqrt{2 \cdot 9.81 \cdot 6370300} = 11{,}050 \text{ m/sec}.$$

We thus have an ellipse when $v_0 < 11,050$ m/sec.
This ellipse becomes a circle when $\epsilon = 0$, i.e.,

$$1 + \frac{r_0^2 v_0^2 \cos^2 \varphi}{\mu^2}\left(v_0^2 - \frac{2\mu}{r_0}\right) = 0.$$

104 Setting

$$\frac{r_0 v_0^2}{\mu} = z,$$

we obtain the condition

$$z^2 - 2z = -\frac{1}{\cos^2 \varphi}; \quad z = \frac{r_0 v_0^2}{\mu} = 1 \pm \sqrt{1 - \frac{1}{\cos^2 \varphi}}.$$

For real φ, this expression is real only if $\cos \varphi = \pm 1$, $\varphi = 0$ or π. In this case,

$$\frac{r_0 v_0^2}{\mu} = 1, \quad v_0 = \sqrt{\frac{\mu}{r_0}} = 7903 \text{ m/sec}.$$

Thus, under the above assumptions, taking practicable launching velocities, we see that the trajectory will be an ellipse; for $v_0 = 11,050$ m/sec, the trajectory will become a parabola, and for $v_0 > 11,050$ m/sec it will be a hyperbola. A horizontal circular trajectory is obtained for 7,900 m/sec.

Let us find the range of a projectile AW and the altitude of the highest point of its trajectory BS. To this end, we first have to find the polar angle $\alpha_0 = OMA$ corresponding to the point A from the equality

$$r_0 = \frac{p}{1 + \varepsilon \cos \alpha_0},$$

which means that the point A should lie on the trajectory. Double the complement of this angle is the angle AMW. Since r_0 is known, we can thus find the range AW. The ascent BS is equal to $MS - r_0$, where MS is the maximum value of r, which is obtained from the equality

$$r = \frac{p}{1 + \varepsilon \cos \alpha},$$

when the denominator takes on its least value, i.e., when $\cos \alpha = -1$. Then

$$r_{max} = \frac{p}{1 - \varepsilon}$$

(also

$$r_{min} = \frac{p}{1 + \varepsilon} = MO,$$

and we can thus find the length of the major axis of the ellipse $r_{max}+r_{min}$).

Thus

$$BS=\frac{p}{1-\varepsilon}-r_0.$$

Numerical example:

$$v_0=820\,\text{m/sec},\ \varphi=44^\circ,\ r_0=6{,}370{,}300\,\text{m}.$$

105 We find

$$\varepsilon=0.99445,\ \alpha=179^\circ41'23{,}6'';$$
$$\frac{AW}{2r_0\pi}=\frac{2(180-\alpha_0)}{360^\circ}=\frac{0.31011}{180}.$$

Hence the range $AW=68{,}958$ m, the altitude 16,620 m, assuming an elliptical trajectory. For the same V_0 and φ, when the trajectory is a parabola,* the range is 68,500 m and the altitude is 16,538 m. The Earth's curvature plays a leading role in these cases, increasing the range by 68,958 minus 68,500 = 458 m. Draw a tangent ADE to r at the point A in the plane of the section through the Earth (Figure 91). Let ASD be a parabolic trajectory corresponding to the range AD. Let $\omega=\varphi$ be an acute landing angle. We see from the drawing that AD is less than AW because of the Earth's curvature. This difference can be found from the following equality

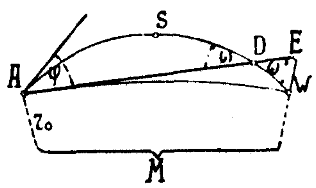


FIGURE 91.

$$AE^2=EW.(EW+2r_0)$$

or, approximately,

$$AD^2=DE.\text{tg}\,\omega.2r_0.$$

De is approximately equal to the sought difference

$$AW-AD=\sim\frac{AD^2}{2r_0\,\text{tg}\,\omega}.$$

In our example this difference is 387 m.

With regular artillery, the Earth's curvature is the only significant factor which affects the range. The variation of g and the convergence of the verticals into one point do not produce a measurable effect.

Let us consider the trajectories of a missile launched from one point A with different (increasing) velocities V_0.

a) Horizontal initial velocity (Figure 92).

* A parabolic trajectory is obtained assuming that the Earth's surface is flat, not spherical, and that all the verticals are parallel to one another.

Let the missile be fired at a point A near the Earth's surface with a velocity v_0. If $v_0 = 0$, the missile will drop to the ground along the local vertical. In this case, the length of the arc of the ellipse degenerates into double the distance from A to the Earth's center M, one of the foci of the ellipse coinciding with M and the other with A. As the initial velocity v_0 increases, the ellipse spreads and its focus shifts from A toward M; for $v_0 = 7{,}900$ m/sec, the missile describes a circular trajectory around the Earth and will continue circling the planet. The variable focus will then
106 coincide with M. As the velocity is increased further, the missile will describe a larger ellipse around the Earth, inevitably returning to the point of origin A. At the diametrically opposite side of the Earth, it will move progressively farther away. When $v_0 = 11{,}050$ m/sec, the missile will not return to the point of origin (not in a finite time, that is) and the ellipse becomes a parabola with the focus at infinity. If the velocity is $v_0 > 11{,}050$ m/sec, the trajectory is a hyperbola with its branches passing through A and gradually approaching the horizontal plane. They will coincide with this plane, however, only in the limit of infinitely large v_0. The moving focus gradually returns from infinity to A.

b) Initial velocity at an angle (Figure 93). If the missile is fired at an angle to the horizon, increasing initial velocity will again produce an elliptical trajectory. The landing site gradually moves away from A. One of the foci of the ellipse is fixed at the Earth's center M, and the other moves along the straight line AF. We can find the direction of this line from the theory of conic sections by erecting a perpendicular AN to the given constant direction of launching at point A and lay off the angle MAN on the other side of AN. (Figure 93 shows a particular case, when AF coincides with the horizontal line through A; this case is observed only if the missile is fired at 45° to the horizon.) A circular orbit cannot be obtained in this case. When the initial velocity is 11,050 m/sec, the ellipse becomes a parabola and the missile does not fall back to Earth. The focus moves to infinity along the straight line AF. We can readily construct the apex of the parabola separating between ellipses and hyperbolas. Through the

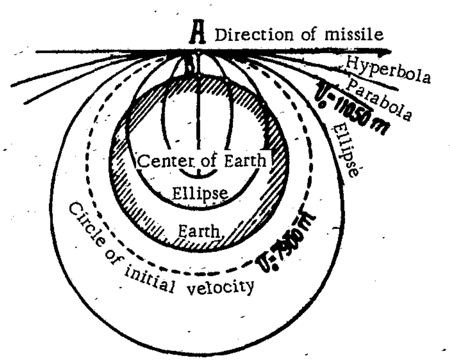


FIGURE 92.

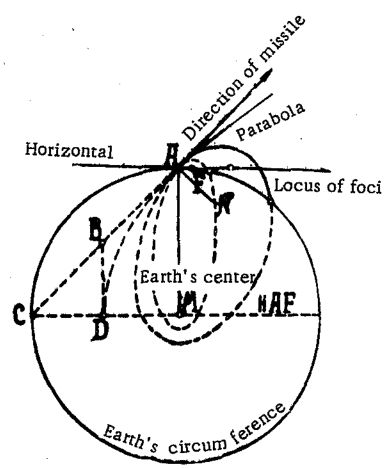


FIGURE 93.

Earth's center ***M***, pass a straight line parallel to ***AF***, bisect the segment ***AC*** between the launching point ***A*** and the intersection point of this parallel line with the circle to obtain the point ***B***, and drop perpendicular ***CM*** from ***B***. The trace ***D*** of this perpendicular is the sought apex of the parabola.

107 *ANNALS AND BIBLIOGRAPHY OF INTERPLANETARY COMMUNICATION*

INTRODUCTION

The idea of man's flight from the Earth to other celestial bodies has its origins in remote antiquity. Long before the Christian era people dreamed about travel to the Moon, Sun and stars. Over the centuries independent ideas have added to the store of knowledge of various methods and possibilities for such a flight; details of the construction of ships and methods for their control, their takeoff from the Earth and their navigation in interplanetary space were elaborated.

Early dreams and fantasies about flights to celestial bodies were directed only to those seemingly in close proximity tothe Earth, i.e., the Moon and Sun. As knowledge of other planets broadened, man directed his thoughts ahead and novelists sent their heroes to Venus, Mars, Mercury, Jupiter, Saturn, Uranus and Neptune.

In the most naive fantasies, in particular those of nomadic peoples, we come across tales of man's flight even to the stars. The scientific and technical approach to this problem came into existence comparatively recently, in 1903, when Tsiolkovskii presented a theoretical foundation for the possibility of the construction of rockets with whose aid man can overcome gravitational forces and take off into interplanetary space. Since then quite a number of scientists and technicians have investigated a series of different questions concerning this problem. Experimental research on rockets was initiated. Reaction-propelled automobiles, sledges, trolleys and airplanes were constructed and investigated.

Novelists, in the wake of scientific thought, anticipate the results and are compelled to envisage in their works new devices and travel to new worlds; fantasy and science go hand in hand and often the scientists come across original ideas in the novels which lead them to interesting discoveries. We may recall, for example, the absorbing novels by Jules Verne.

Throughout their historical development ideas about interplanetary communications have been interwoven and go hand in hand with diverse sciences; the problem of rockets and their mechanism, the application of ordinary and electric guns, centrifugal machines, the study of effective kinds of fuel, liquid hydrogen and oxygen, properties of materials for the construction of spaceships, problems of energy transfer in space, radio communication, flight conditions in outer space, properties of the interplanetary atmosphere and the radiant energy in it, etc. For this reason, the reader may find that the annals and bibliography presented below cover a wide range of topics: from legends to mathemathical research, from fiction to experiments with jet machines, although only those works which are relevant to the problem that concerns us are mentioned. The vital importance of the idea of interplanetary communication is demonstrated by the increase over the centuries and years in the number of works dealing with it. Thus, 32 references date back to the pre-Christian era, from the beginning of the Christian era until the 17th century there are 18 references, in the 17th century 30, in the 18th century 19, in the 19th century 144 and in the 20th century 1,140 references.

The most vigorous development of the literature dealing with interplanetary communications has been observed during the 20th century, i.e., in our own time, as expressed in the following table.

1900 – 1909	63	
1910 – 1919	131	
1920	14	
1921	12	
1922	12	
1923	41	
1924	66	
1925	57	
1926	86	
1927	108	
1928	205	
1929	121	information incomplete
1930	126	
1931	85	
1932	13	

The author of this article has collected 1,233 books, articles and notes relevant to the topic under discussion; yet this collection is, of course, far from complete in its coverage of the problem, in particular for the years 1929, 1930, 1931 and 1932 when it was extremely difficult to obtain foreign literature.

The bibliography of interplanetary communications cited below is divided into five sections:

1. Russian-language fictional works.
2. Non-Russian fictional works.
3. Motion pictures.
4. Russian-language publications of scientific research and popular science.
5. Non-Russian publications of scientific research and popular science.

In the index are listed a total of 1,233 titles of works of which 197 are included in the 1st section, 81 in the 2nd, 12 in the 3rd, 447 in the 4th, and 498 in the 5th.

The reader interested in details concerning interplanetary communications can find them in the following works.

Rynin, N. A. Mezhplanetnye soobshcheniya (Interplanetary Communication). *

No. 1. Mechty, legendy i pervye fantazii (Dreams, Legends and Early Fantasies). Leningrad. 1928.

No. 2. Kosmicheskie korabli v fantaziyakh romanistov (Spacecraft in Science Fiction). Leningrad. 1928.

* [English translation by IPST, Jerusalem, 1970—1971. NASA TT F-640—648; TT 70—50111—50119.]

No. 3. Luchistaya energiya v fantaziyakh romanistov i proektakh uchenykh (Radiant Energy: Science Fiction and Scientific Projects). Leningrad. 1928.

No. 4. Rakety (Rockets). Leningrad. 1931.

No. 5. Teoriya reaktivnogo dvizheniya (Theory of Rocket Propulsion). Leningrad. 1929.

No. 6. Superaviatsiya i superartilleriya (Superaviation and Superartillery). Leningrad. 1929.

No. 7. K. E. Tsiolkovskii. Ego zhizn', raboty i rakety (K. E. Tsiolkovskii: Life, Writings, and Rockets). Leningrad. 1929.

No. 8. Teoriya kosmicheskogo poleta (Theory of Space Flight). Leningrad. 1931.

No. 9. Astronavigatsiya. Letopis' i bibliografiya po mezhplanetnym soobshcheniyam (Astronavigation. Annals and Bibliography of Interplanetary Communications). Leningrad. 1932.

In addition, H. Oberth's "Wege zur Raumschiffahrt" (3rd German edition) is now in press.

With regard to any problems that may arise in connection with the cited works on interplanetary communications, the reader is kindly requested to contact the author at the following address: Nikolai Alekseevich Rynin, Leningrad, ul. Zhukovskogo No. 4, apt. 9.

PRE-CHRISTIAN ERA

The following annals of the development of the idea of interplanetary communications was compiled mainly from the numerous works dealing with this topic. The reader wishing to obtain more detailed information on the topic presented in the annals will in most cases find bibliographical references in the following section "Alphabetical Index of Works on Interplanetary Communications" according to the surname of the author mentioned in the annals or according to the title of the work if the article is anonymous.

Indian manuscripts. 4 million – 9546 B.C. Flights on rocket-powered airplanes in Atlantis.

Chinese legends. The first Chinese god-prince (the son of heaven) descended from heaven.

Peruvian legends. The founder of the first Peruvian dynasty, Manco Guella, descended from the sky with his wife.

Mexican myths. The Mayas, inhabitants of ancient Mexico, believed that their gods descended from heaven on a spider's web.

Egyptian myths. Habitation of the stars, planets and the Moon.

Hindu legends. According to legend, Rajpoots (Sur'yavanzy)* of India are descended from the Sun, but Brahmins (Induvanzy)** from the Moon.

Hindu Vedas. Transmigration of the soul from the Earth onto other celestial bodies.

Râmâyana. Flight of Sampati and Eataius on wings to the Sun.

Babylonian legends. Flight of Etana to Heaven on an eagle circa 3000 B.C.

Arabian fairy tales. Flight of the son of the Persian emperor to the Sun on a magic horse.

—Flight of Sindbad the Sailor to the angels on a winged man.

Bible. Interruption of the motion of the Sun and Moon by Jesus Christ.

—Ascent of Elijah the Prophet to heaven on a horse-drawn chariot.

—Ascent of Enoch to heaven.

The Persian poet Firdausi. Flight of the Shah Kei Kaus to the sky with the help of eagles.

* [Members of Hindu soldier caste.]

** [Member of Hindu priestly caste.]

Japanese legend. The god Suzano lived on the Moon and descended to Earth.
Metamorphoses of Ovid. Flight of Icarus on wings to the Sun.
Arabian historian Tabari. Flight of the emperor Nimrod on griffins to join battle with God.
Ancient China. Unsuccéssful flight of the madarin P'an Ku on rockets and a kite.
— Rocket launching of fire arrows.
1194–1193 B.C. The Chinese Emperor Wu-yi shoots an arrow into the sky.
Finnish Epics of Kalevala. Flight of a bee to the Sun, Moon, and stars. Flight of a bear from the sky to the Earth. Capture of the Sun and Moon and their liberation.
12th century B.C. Launching of arrows into the sky from the Tower of Babel.
330 B.C. Alexander of Macedonia's flight to the sky on birds.
3rd century B.C. Hero's jet steam engine.
210 B.C. Archimedes' rays for the ignition of ships.
Diogenes, Laërtius. Legend of the selenite descent to Earth (evidence of Heraclitus).
Circa 100 B.C. Menippus' voyage to the Moon on a waterspout (a tale by Lucian).
94 B.C. Opinion of the philosopher Lucretius regarding the inhabitants of other worlds.
— Celtic belief of the inhabitation of the Moon and of the transmigration of their souls to the Sun.

FROM THE YEAR 1 A.D. to the 17th CENTURY

Beginning of the Christian era.
Ascent of Jesus Christ to heaven.
The ecstatic journeys of Saint Paul in the stellar spheres.
The corporeal ascent of the Virgin Mary to heaven.
66 A.D. Flight of Simon the Magician with the help of evil spirits.
2nd century. Lucian of Samosata's "Icaromenippus" and "True Story" (Αληθοῦς ἱςτορίας (English translation by A. M. Harmon, Princeton University).
399. A celebration with rockets in Milan.
630. Mohammed's Koran. Mohammed's flight to God's throne on a winged being, "Borak"
Middle Ages. A missionary's journey to the sky on foot.
Middle Ages. Kirchner. The ecstatic journey of Kirchner to the stellar spheres.
1313. Dante. The ecstatic journey of Dante in the stellar spheres.
1379. Muratori's report that rockets can be utilized in Western Europe.
15th century. Astolph's voyage to the Moon in a horse-drawn chariot.
1405. Elevation of a kite balloon by means of the rocket system of Konrad Keyzer von Eichstädt.
1420. Joanes de Fontana suggests that rocket engines be used to launch missiles in the form of hares and birds to frighten enemies. The rocket chariot is his suggestion also (Ikarus, p. 62. 1928).
16th century. Rocket launching from a machine.

17th CENTURY

1634. Kepler. Mathematici alim. Imperatorii Somnium, sui opus posthumus de Astronomia lunari. Frankfort.

1638. Domingó Gonsales' flight to the Moon on swans.

1640. Stories of one hundred journeys to the Moon since the time of Galileo.

— Wilkins' plan to fly to the Moon with the help of chariots and birds.

— J. Wilkins' work, "A Discourse concerning a New World" with a description of flight outside the gravitational sphere.

1642. Godwin, Francis. "The Man in the Moone." England.

1649–1652. Cyrano de Bergerac's projects for flight to the Sun and Moon with the help of 1) dew on the body, 2) wings and springs, 3) rockets, 4) bulls' marrow, 5) a parachute based on Montgolfier's principle, 6) a magnet, 7) attraction of the Moon, 8) a devil, 9) dew in vials, 10) rarefied air, 11) willpower, 12) eagles.

17th century. Marsenne and Petit's shot from a gun into the sky. David Fabricius's observations on selenites.

1660. Kirscher, Athanasius: "Itinerarium extaticum" (Würzburg).

— Daniel, Gabriel: "Voiage du monde de Descartes." English translation, 1694: "A Voyage to the World of Cartesius."

1665. Rotation of the Earth's axis by angels, according to J. Milton.

— Alteration of the Sun's path by the Most High, according to J. Milton.

1666. Newton's idea of interplanetary rocket flight.

1670. Fabry's rocket flying machine.

1686. Newton's rocket steam automobile.

1692. Flight of the soul to the Moon (according to a work by Daniel).

— Fontenelle's Dialogues on the plurality of worlds.

1698. Christianus Huyghens. "Κοσμοθεωρος, sive de terris coelestibus earumque ornatu conjecturae. "English translation, 1698: "Cosmotheoros: or Conjectures Concerning the Planetary Worlds and Their Inhabitants."

18th CENTURY

1700. Daniel Defoe's work "The Consolidator," with a description of flights in outer space and to the Moon.

1703. David Russen. "Terraqueous Globe." London.

1711. Gongam's flight on a magic arrow.

1720. 'sGravesande's investigation of a trolley which could be propelled by the force of a steam jet.

1727. Swift's magnetic ship.

1740. Robert Paltock: "Peter Wilkins' Journey to the Moon," England.

1742. Kindermann's visions of flights to Jupiter.

1744. Flight of five men on evacuated air balloons to a satellite of Mars (according to Kindermann).

1750. Segner's rocket wheel.

— "Relation du Monde de Mercure."

1752. Micromegas' voyage on a sun ray and on a comet past the heavenly bodies, to Saturn and the Milky Way (according to Voltaire).

1758. The voyage of Swedenborg's soul to the planets.

— Swedenborg: "Arcana Coelestia." "De Telluribus in Mundo Nostro."

1765. Roumier, Marie-Anne, de: "Voyages de Milord Ceton dans les sept planètes," 7 parts. The Hague. (Milord Ceton's journey past the seven planets on the wings of a spirit and to Jupiter in the form of atoms.)

1775. Voyage of the inhabitants of Mercury, the "Scintillae," to Earth in an electric ship.

1783. The Montgolfiers' works on rocket flight.

— The Montgolfier air balloons of Mioland and Janiner.

1784. Gerard's rocket ornithopter.

— Ramsay's rocket ship (water-powered).

End of the 18th Century and 1804. Congreve's rockets.

19th CENTURY

Beginning of the 19th Century. Optical signaling on the Moon according to Gauss.

— Inner drilling of rockets according to Schumacher.

1805. Congreve's rocket gun.

— Flight of the hero of Dumas' novel to the Moon, with the help of an eagle.

1806. Ascent of a ram on a rocket (Claude Ruggieri).

1807. Use of rockets in the bombing of Copenhagen.

1821. English caricature on rocket flight.

— Fontenelle, Bernard de Bouvier de: "Entretiens sur la pluralité des mondes habités." Paris.

1827. Joseph Atterley. "Voyage to the Moon: with some Account of the

— Manners and Customs, Science and Philosophy of the People of

— Morosofia and of the Lunarians." New York (dealing with antigravitation).

1833. Flight of a witch to the stars and of the Devil to the Moon.

— Flight of the blacksmith Vikula to the Moon and stars on a devil (according to Gogol).

— Flight of a hussar to the stars (according to Pushkin).

1835. Hans Pfaall's flight to the Moon in a balloon (according to Edgar Allan Poe.) (Poe, Edgar Allan: "The Unparalleled Adventures of one Hans Pfaall." Southern Literary Messenger, June).

— John Herschel's telescope for the observation of selenites: "Great Astronomical Discoveries Lately Made by Sir John Herschel at the Cape of Good Hope.— The Sun, New York. August.

— A rarefied air condenser, according to Edgar Allan Poe.

— Rebenstein's rocket airplane project.

— Laplace's ideas about inhabitation of the planets.

1836 (?) The Viennese astronomer Littrow's idea of setting up an optical system for signaling to the Moon).

1838. Boitard's voyage to the Sun and planets on an aerolite.

1841. Golightly's patent, in England, of a rocket steam airplane.

— Feldhaus's article on the history of rescue rockets.

1843. Zhir's rocket balloon.

1844. Selligue's rocket ship (gas reaction).

1846. Hale's jet rockets.

1847. J. L. Riddell: "Orin Lindsay's Plan of Aerial Navigation; with a Narrative of his Explorations in the High Regions of the Atmosphere, and his Wonderful Voyage around the Moon." New Orleans. (Work dealing with antigravitation).

1849. Washington Irving: "Life of Mahomet," pp. 24, 27, 28, 79, 80, 89 of Russian edition.

— Steam, gas, and air rockets of Tretesskii.

1850. Konstantinov's rocket fire ships and hydrogenation flasks.

1860. Gas-powered rocket aircraft.

— The rocket helicopter.

1861. Hale's rockets — simple and revolving.

1865. Voyage to the Moon with the aid of minus-matter (according to A. Dumas).

— Camille Flammarion. Fictitious and real worlds.

— Camille Flammarion: "Les mondes imaginaires et les mondes réels." Paris.

— Eyraud, Achille. A novel including a description of a rocket for flying to Venus.

— Jules Verne: "De la terre à la lune."

1865—1869. Afanas'ev, A. "Poeticheskie vozzreniya slavyan na prirodu" [Slavic Poetical Ides on Nature], Vol. 3, Parts 1—3. Moskva.

1866. Sokovnin's rocket dirigible.

1867. Butler and Edward's winged rocket.

1870. Jules Verne: "Autour de la lune." [Around the Moon.]

1870—1913 (?). The two-stage rocket of Colonel Boxer.

1870 (?). Capture of Tashkent by General Chernyaev with the help of 30 rockets.

1871. Tridon's plan of an air balloon with a hermetic gondola.

1873. Pressure of light rays and transfer of material particles in outer space, according to Maxwell.

1874. Flight to the Moon from the barrel of a gun (according to Jules Verne).

1875. Rotation of the Earth's axis by the firing of a cannon (according to Jules Verne).

— A gun missile becomes an Earth satellite (according to Jules Verne).

— Barbican's telescope for observing the flight of the missile to the Moon (according to Jules Verne).

— Man's respiration in outer space (according to Jules Verne).

1877. Jules Verne. "Hector Servadac" (fiction).

1878. Gützler's rocket missile.

19th Century. Zellner's thermal rocket pendulum.

Circa 1800. Ehrenhaft's theories on radiation pressure.

1880. Canton: "General Natural History and the Theory of the Heavens" (essay).

— Barnaby's experiments in England during an investigation of hydraulic jet engines in ships. — Jl. R. aeronaut. Soc., p. 29. January. 1931.

— Carl de Prel: "Die Planetenbewoner und die Nebularhypotese." Leipzig.

1881. Butler and Edward's patent for a winged rocket.

— Kerchove and Snyerr's reaction engine with detonating gas.

— Kibal'chich's rocket craft.

1882. Pul'k Rabek's rocket dirigible.

— Carl de Prel: "Entwicklungsgeschichte des Weltaus." Leipzig.

1883. Tsiolkovskii's manuscript: "Izmenenie sily tyazhesti" [Modification of the Force of Gravity].

— Radiation pressure, according to Bartoli.

— Langley's opinions on radiation pressure.

— Description of Barnaby's experiments in England during an investigation of hydraulic jet engines in ships. — Proc. Instn. civ. Engrs., **77**:1. 1883; Jl. R. aeronaut. Soc., p. 29. January. 1931.

1884. Camille Flammarion: "Les terres du ciel; voyage astronomique sur les autres mondes."

1885. Camille Flammarion: Space flight of two men from Earth to Mars on a comet.

— Camille Flammarion: "Rêves étoilés." Paris.

— Meyer, M.: "Die Königin des Tages und ihre Familie." Vienna.

1886. Ciarcu's rocket boat.

— Geshvend's rocket steam locomotive.

1887. Geshvend's rocket steam craft.

— Manned flight on a comet and descent to Earth in a Montgolfier balloon (according to Jules Verne).

1888. Artificial attraction of the Moon to the Earth by a magnet (according to Laury).

— Bourdon's gas-pressure multiplier.

— Connection of the Moon and the Earth by a pipe (according to Laury).

— The French rocket dirigible.

1889. Le Faure and Graffigny's ideas: 1) the Selenite rocket ship (water- and gas-powered); 2) voyage of a Russian scientist on a comet from Mercury to Mars; 3) descent of the Russian scientist by balloon towards Mars's satellite "Phobos;" 4) a suction-jet rocket craft for flight in the asteroid belt between Mars and Jupiter; 5) a ship propelled by expansion of radiation; 6) Martian ship (screw propeller and pipe) for flight in Mars's atmosphere; 7) telephone between the Moon and Venus; 8) from a cannon to the Moon; 9) from the volcano Cotopaxi to the Moon; 10) pressurized space suits; 11) radiation pressure of the Sun

1890. The adventures of Baron Munchausen: 1) flight on a bullet; 2) voyage to the Moon on a plant; 3) voyage to the Moon by hurricane.

— Ganswindt's first reports of a rocket ship.

— Astor. 1) Apergetic ship; 2) electric light signaling from the Earth to outer space; 3) Astor's telescope with 20-meter diameter lens; 4) rotation of the Earth's axis by a change of mass at the Poles; 5) alteration of the Earth's orbit by apergia. Fiction.

— An American rocket dirigible.
— Heliograms from the Earth to Mars.

1891. Trouver's explosive ornithopter.
— P. Lebedev's first report of light radiation pressure.
— Utilization of the radiant energy of outer space for rocket ships, as proposed by Nernst, Wiecherts, Scharpeller, and Sargent.
— Use of the rocket for photographing the Earth; Rohrmann's patent.
— N. A. Morozov's interplanetary ship.
— Flight in four-dimensional space, according to N. A. Morozov.

1892. Lyakide's ornithopter for flying to the planets.
— Petersen's rocket dirigible (Mexico).
— Lavarenne's rocket ship.
— P. Lebedev's experiments on the effect of radiation pressure.
— Flammarion. 1) Natural flight to the planets of the constellation "Deva;" 2) flight of the soul to the planets and stars.
— "Zhiteli planet" [Inhabitants of the Planet]. — N. Strakhov's article.
— "Mir kak tseloe" [The World as a Whole].
— C. Flammarion: "Uranie." (A voyage in outer space.). Paris.
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— Lavarenne's patent (German and French) for the application of the jet in the dirigible.

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— Gansvindt's interplanetary rocket ship.
— Goethe. Homunculus (the essence in the water).
— Tsiolkovskii. "Na Lune" [On the Moon]. A story.
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1894. John Jacob Astor's work "Journey in Other Worlds."

1895. Tsiolkovskii. 1) Disintegration of the planets by solar energy; 2) control of motion of asteroids by breaking them into fragments; 3) project for experiments on the effects of acceleration on living beings; 4) flight of a cannonball carrying a passenger into outer space.
— Herbert's rocket wing.
— Reiter's rocket ship.
— Hoeft's solenoid gun for an interplanetary rocket ship.
— Hoeft's interplanetary rocket ship.
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— P. Lebedev's experiments for determining intensity of light pressure.
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— Tsiolkovskii: "Na planetakh" [On the Planets]. Manuscript.

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— C. Flammarion. "Lumen." Conversations on the immortality of the soul [Russian edition].

20TH CENTURY

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— Tesla's note on universal electric rays and electric signaling on the planets.
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— Hergezell's experiments in Germany with radio-controlled balloon sondes.
— Wells. 1) Heat rays as a Martian weapon; 2) shooting of a passenger-bearing projectile from Mars to Earth.
— Balloon flight of two Frenchmen from Earth to the Moon (fiction).
1901. Wappler's rocket dirigible.
— Wells's gravitation screen.
— Nichols and Hull's experiments on the effect of radiation pressure.
— "Vystrel s Marsa" [A Shot from Mars]. Note in the journal "Priroda i Lyudi." 1901.
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— The Heaviside Layer.
— Wells's "The Time Machine".
1903. Theory and design of rocket flight in space according to K. Tsiolkovskii.
— Tsiolkovskii's direct-nozzle rocket.
— Torres Quevedo's experiments on remote control of boats by radio.
— M. Filippov's rays for remote-controlled detonation.
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— Kryzhanovskaya's interplanetary electric ship for flight from the Earth to Mars and back.
— Lorenz. The escape of gases from tubes of variable cross section.
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(?) The rocket device of Ventoux and Duclos.
– Flight of Ivanushka-Durak on the Humpback Horse to the Sun and Moon.
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1908. Lorin's rocket airplane.
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– Ferber's concept of the conquest of outer space.
– Semenov. Detonator rays for disintegrating matter; 2) "generator" and "neogenerator" ships.
– Bogdanov. 1) Air-ship; 2) Ether-ship; 3) telescope with a diamond objective.
– Wells: "The Plattner Story" (Flight in four-dimensional space).
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– Interruption of the Earth's rotation in accordance with human will (Wells).
– Hammond's experiments on radio control of aircraft.

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- — Crocco's opinions regarding rocket space flight.
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