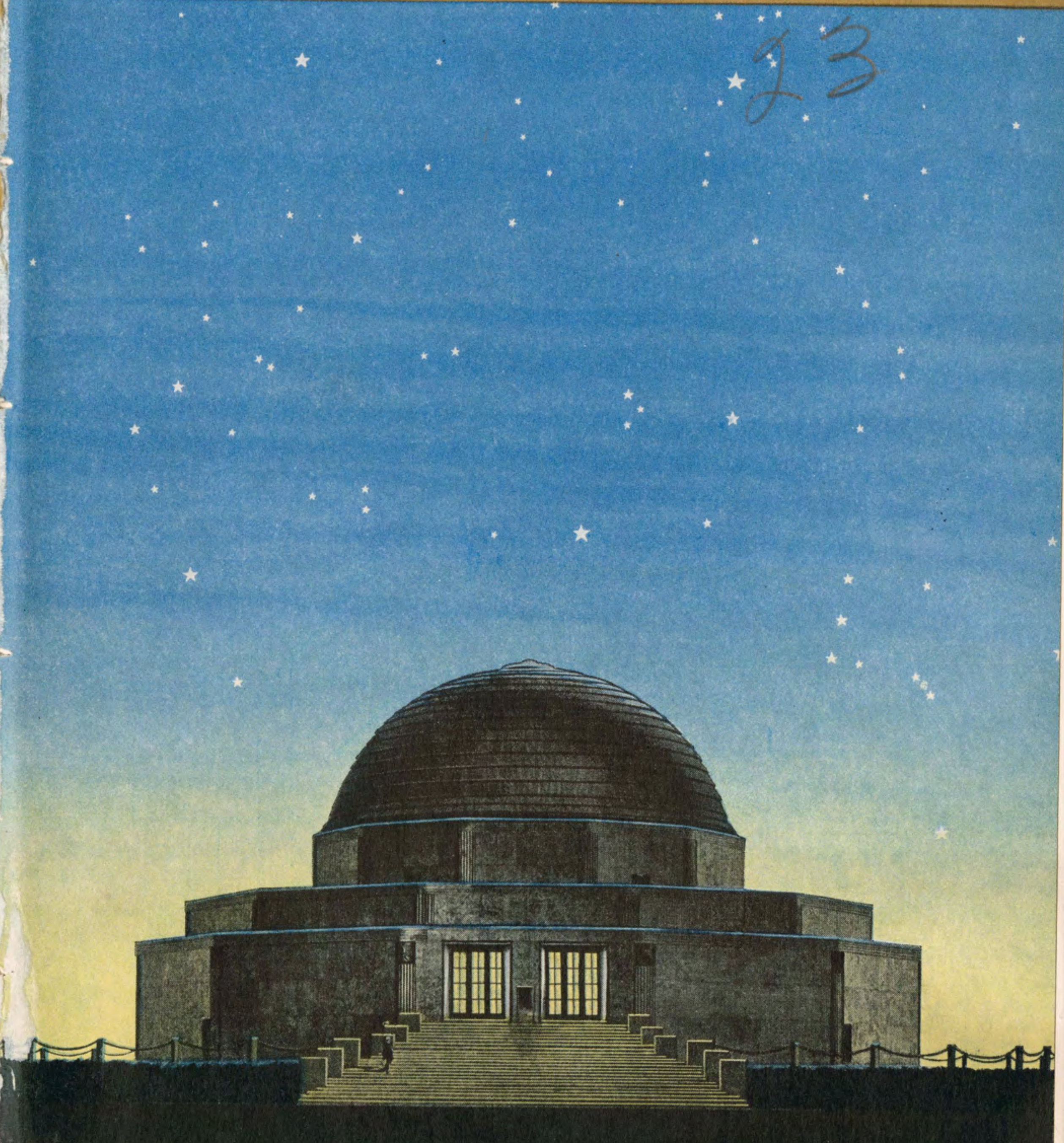
ADLER PLANETARIUM AND ASTRONOMICAL MUSEUM OF CHICAGO

PHILIP FOX



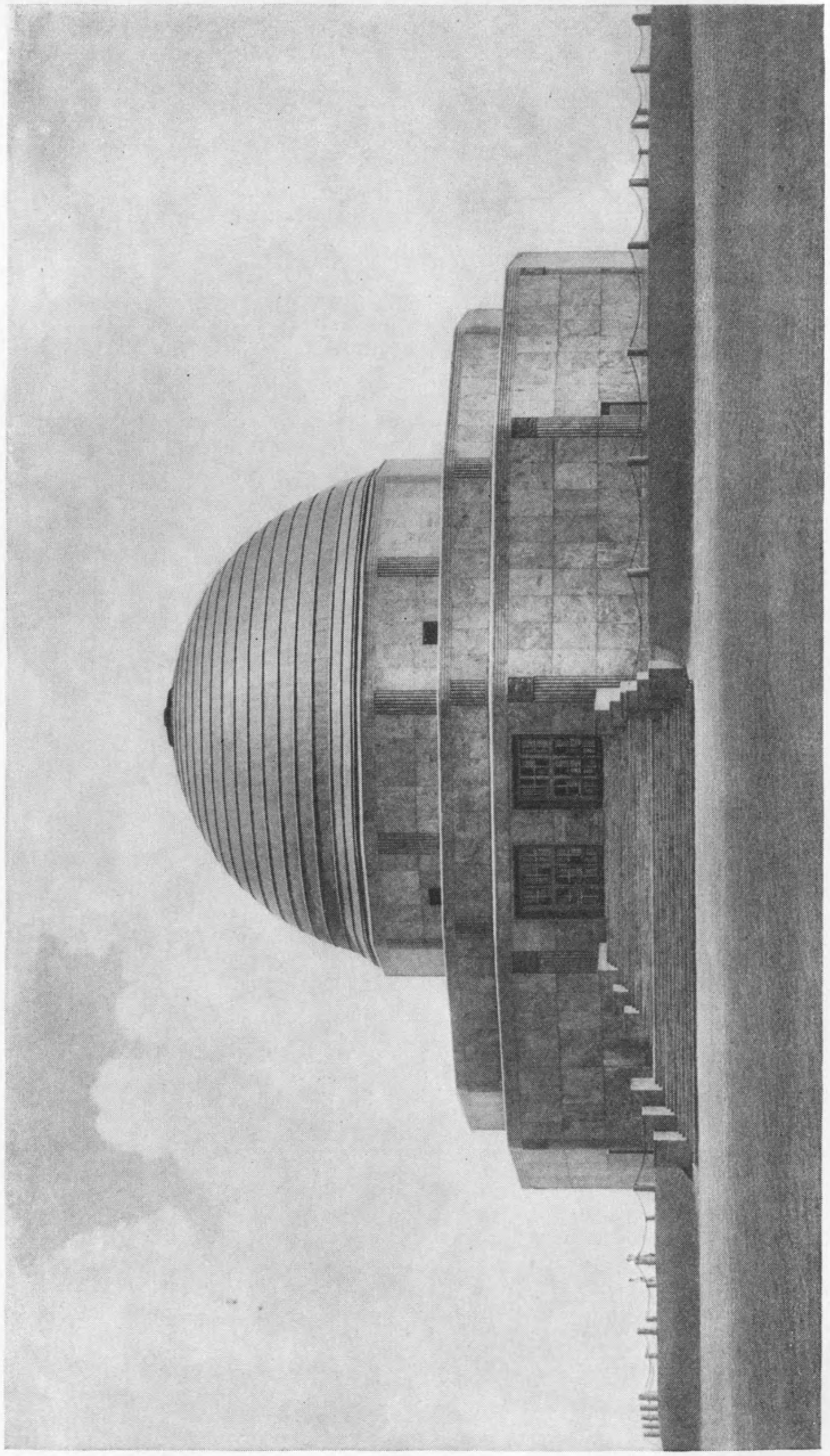


PLATE I. ADLER PLANETARIUM AND ASTRONOMICAL MUSEUM

ADLER PLANETARIUM AND ASTRONOMICAL MUSEUM

An Account of the Optical Planetarium and a Brief Guide to the Museum

BY PHILIP FOX

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CHICAGO

THE ADLER PLANETARIUM AND ASTRONOMICAL MUSEUM OF CHICAGO[1]

BY PHILIP FOX, DIRECTOR

OVER the world there are many museums of art, where are collected masterpieces from the brush, the chisel, the goldsmith's table, the potter's wheel, or the loom,—things which bear witness to man's agelong striving for the expression of beauty, in form or color or texture. Fewer, however, are the museums where one may look for evidence of man's intellectual awakening expressed in the development of his powers of reason; and fewer still, but of growing importance, are the museums of the physical sciences. These museums come as powerful aids to the great libraries, storehouses of learning.

If all persons could be informed of the successive advances of science, if the phenomena and the laws which govern them and which may be derived from orderly consideration of them could be presented in such way as to win general understanding, the progress of learning would be greatly accelerated. It should be the aim of every museum of science to exhibit its material with this end in view. Such attempts in the natural sciences have perhaps been more extensive and perhaps more successful than those in the physical sciences. One sees many interesting and instructive exhibits in numerous museums of Natural History. It is more difficult to prepare in form for easy comprehension exhibits to illustrate the phenomena and laws of those sciences which walk hand in hand with mathematics.

The Adler Planetarium and Astronomical Museum of Chicago, an institution of type quite new to America, opened its doors to the public on 12 May 1930. The institution had been dedicated, and presented to the South Park Commissioners, on the tenth of May in the presence of a distinguished company. It is natural for one interested in astronomy to inquire how this institution came into being, how it is housed, what may be seen there, what is its purpose, and what response the public has given to its offerings.

Its origin may be found in the development at Jena of the optical planetarium and in the generosity of the donor, Mr. Max Adler of Chicago. Mr. Adler's aim is well expressed in the following quotations from his presentation address:

"Chicago has been striving to create, and in large measure has succeeded in creating, facilities for its citizens of today to live a life richer and more full of meaning than was available for the citizens of yesterday. Toward the creation of such opportunities I have desired to contribute.

"The popular conception of the universe is too meager; the planets and the stars are too far removed from general knowledge. In our reflections, we dwell too little upon the concept that the world and all human endeavor within it are governed by established order and too infrequently upon the truth that under the heavens everything is interrelated, even as each of us to the other."

And again, "The planetarium has been the subject of praise by scientists and educators. One of them has characterized it as

[1]Grateful acknowledgment is made to Carl Zeiss Inc. for certain illustrative photographs; to Mr. F. W. Schlesinger, Demonstrator, for aid in the preparation of diagrams and photographs; to Professors O. F. Long of Northwestern University, Campbell Bonner of the University of Michigan, and Roy C. Flickinger of the University of Iowa, for the translation of Latin inscriptions on various instruments; and to Miss Maude Bennot, Assistant Director, for valuable aid in the preparation of this account, in the examination of museum pieces and their arrangement in the Museum, and in the formulation of the program and all elements of the administration of the Planetarium and Museum.

'a school-room under the vault of heaven' and as 'a drama with the celestial bodies as actors.'

"It is my hope that the youth of our city, and indeed of other cities, may through this dramatization find new interests and fresh inspiration and also that with the aid of the Planetarium and Astronomical Museum, science may be advanced."

Though this Chicago institution bears a double name and is commonly referred to as the Planetarium, it is in reality an Astronomical Museum of which the Planetarium instrument is the principal exhibit.

It stands on an island in Lake Michigan to the east of those neighboring institutions, the Field Museum of Natural History and the Shedd Aquarium. The three are fittingly closely associated and form a trinity dedicated to the study of "The Heavens above, the Earth beneath, and the waters under the Earth." During 1933 the buildings of the Century of Progress Exposition housing the accomplishments of science, industry and general social progress are additional neighbors.

The approach to the building from the west is a broad esplanade with walks and roadways flanking a series of twelve shal-

MR. MAX ADLER OF CHICAGO, FOUNDER AND DONOR.

low pools, each 16 feet wide and 26 feet long, on the bottom of which in colorful terrazzo are designs symbolic of the months of the year.

The building is an imposing edifice of rainbow granite with copper dome. The plan (Fig. 1) shows that its shape is a regular dodecagon. The exterior diameter is 160 feet. Inset at the exterior corners are bronze plaques of the twelve Signs of the Zodiac by Alfonso Iannelli. Those for Leo and the Gemini have been selected as representative (see page 8). Usually, when figures of the Zodiacal Signs are used for exterior decoration they are arranged as on a celestial globe, as though the sky were projected upon the surface, in which case they would be placed successively in counter-clockwise order. The sculptor had, however, nearly finished his modelling with the figures reversed, as on the usual map, before the astronomical director saw the plaques. It was therefore necessary to mount them in clockwise sequence, a permissible arrangement if they are regarded as maps held

DEDICATION PLAQUE.

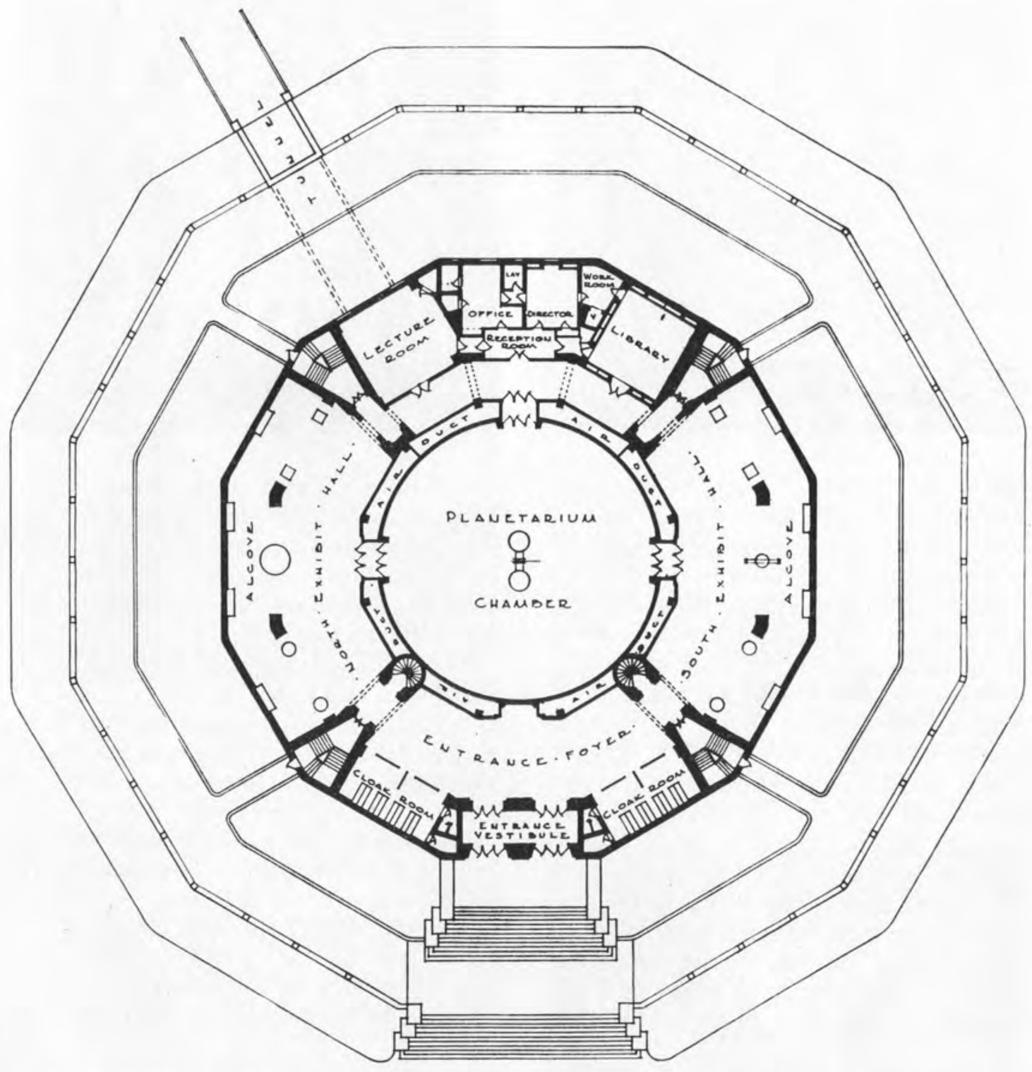


FIG. 1. PLAN OF THE MAIN FLOOR SHOWING LOCATION OF THE PLANETARIUM CHAMBER, THE SURROUNDING MUSEUM CORRIDORS, OFFICES, AND ENTRANCE FOYER.

aloft to match the sky. The stars are placed on the sculptured figures in positions fitting the descriptions of Ptolemy, or perhaps it were better to say that the figures were designed to fit the requirement of the fixed framework of stars.

Centrally located within the building is the circular planetarium chamber 72 feet in diameter, carrying a hemispherical dome of 68 feet diameter. This is the diameter recommended by the makers of the instrument. With a larger dome, the stars lose brilliancy and if much smaller, the illusion of the open sky is lost. The linen of the dome is stretched over horizontal battens circling the dome like almucantars. The whole is suspended by metal straps from the outer dome (see Fig. 2). The outer dome has a diameter of eighty feet and is non-concentric with the linen surface. This arrangement results in favorable acoustics unless the speaker stands too near the cen-

ter of the chamber. An air-conditioning unit by the Carrier Engineering Corporation installed in preparation for the intensive use during the Century of Progress Exposition keeps the planetarium chamber at comfortable temperature. It is better to show noonday with the cool of evening than evening with the heat of noon.

About the central hall are the entrance foyer, museum corridors, offices, library, and a small lecture room. The entrance faces to the west; the offices look to the east on Lake Michigan. Over the offices there is a room for bookstacks and instruments. The lower floor of the building (Fig. 3) contains the main museum space, a lecture room seating 170, rest rooms, instrument shops, photographic dark room, and the heating, ventilating, and air-conditioning installations. There is a broad upper promenade deck for view of the sky. Portable instruments are carried there on clear evenings. The coelostat for throwing the solar image into the museum chamber below is also on this deck.

The building is regarded as of such merit that for its design the architect, Ernest A. Grunsfeld, Jr., was awarded the 1931 gold medal of the Chicago Chapter of the American Institute of Architects.

Probably the first natural phenomenon to impress itself on man as he began to observe and reason was the orderly succession of day and night. And while he was grateful to the Sun for its light and warmth and the protection and comfort which it afforded, he marvelled no more concerning

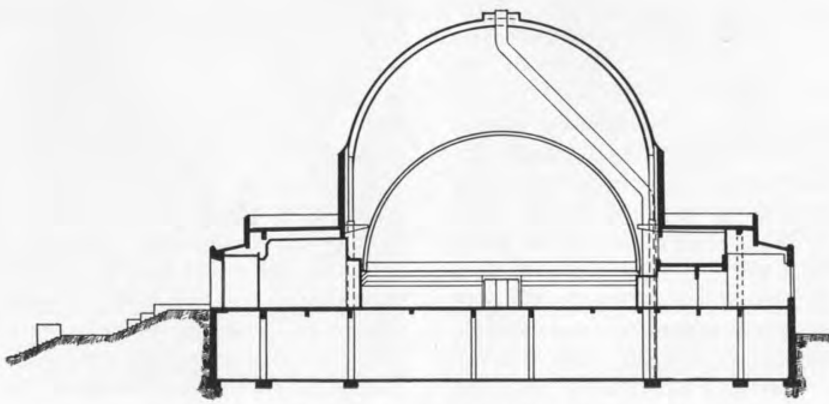


FIG. 2. CROSS-SECTION OF THE BUILDING IN ELEVATION.

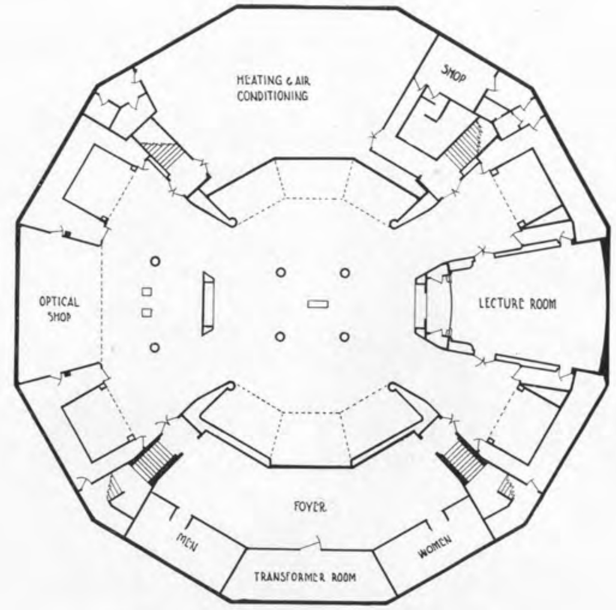


FIG. 3. PLAN OF THE LOWER FLOOR.

the Sun than he did about the stars wheeling in the night sky.

> "Thinketh he dwelleth i' the cold o' the Moon
> Thinketh he made it and the Sun to match
> But not the stars, The stars came otherwise."

He saw the Moon and traced her course among the stars in recurrent phases and saw the brighter planets threading their complex ways. It was long before he was able to unify these phenomena into an harmonious scheme of action, in fact, not until Ptolemy (100–170 A.D.) made his Earth-centered hypothesis with its complex system of epicycles. This hypothesis yielded reluctantly to the Sun-centered theory of Copernicus (1473–1543).

After the announcement of these theories, ingenious men began to make models to represent by means of globes suitably geared together, the observed or calculated motions of the planets and Moon and later also of the other satellites. Not the first, for it is stated that such models date back to Archimedes, but among the earlier of them is that of Christian Huygens constructed in 1682 by the horologist Johannes van Ceulen de la Haye. This may still be seen at the Observatory of Leiden. It is of interest to know that in the calculations for the gearing Huygens came to the invention of continued fractions. These instruments were developed until they became very serviceable in illustrating the phenomena of day and night, of the seasons, of lunar phases, eclipses, transits, occultations, all planetary configurations.

At a date between 1700 and 1710 George Graham, inventor of the compensated pendulum, constructed for Prince Eugene an instrument to show most of the above phenomena. John Rowley copied this instrument with some additions and improvements for the Earl of Orrery. In this lies the origin of the name "orrery" as applied to later elaborate mechanical planetaria. Such instruments varying in size and complexity are to be found widespread. A very interesting one is that made by Eise Eisinga at Franeker, Holland, between 1773 and 1780. In America those by David Rittenhouse, begun in 1767, are worthy of mention: one is at present preserved in Philadelphia. The Rittenhouse planetarium is described in the first volume of the *Publications of the American Philosophical Society*. Perhaps also should be mentioned

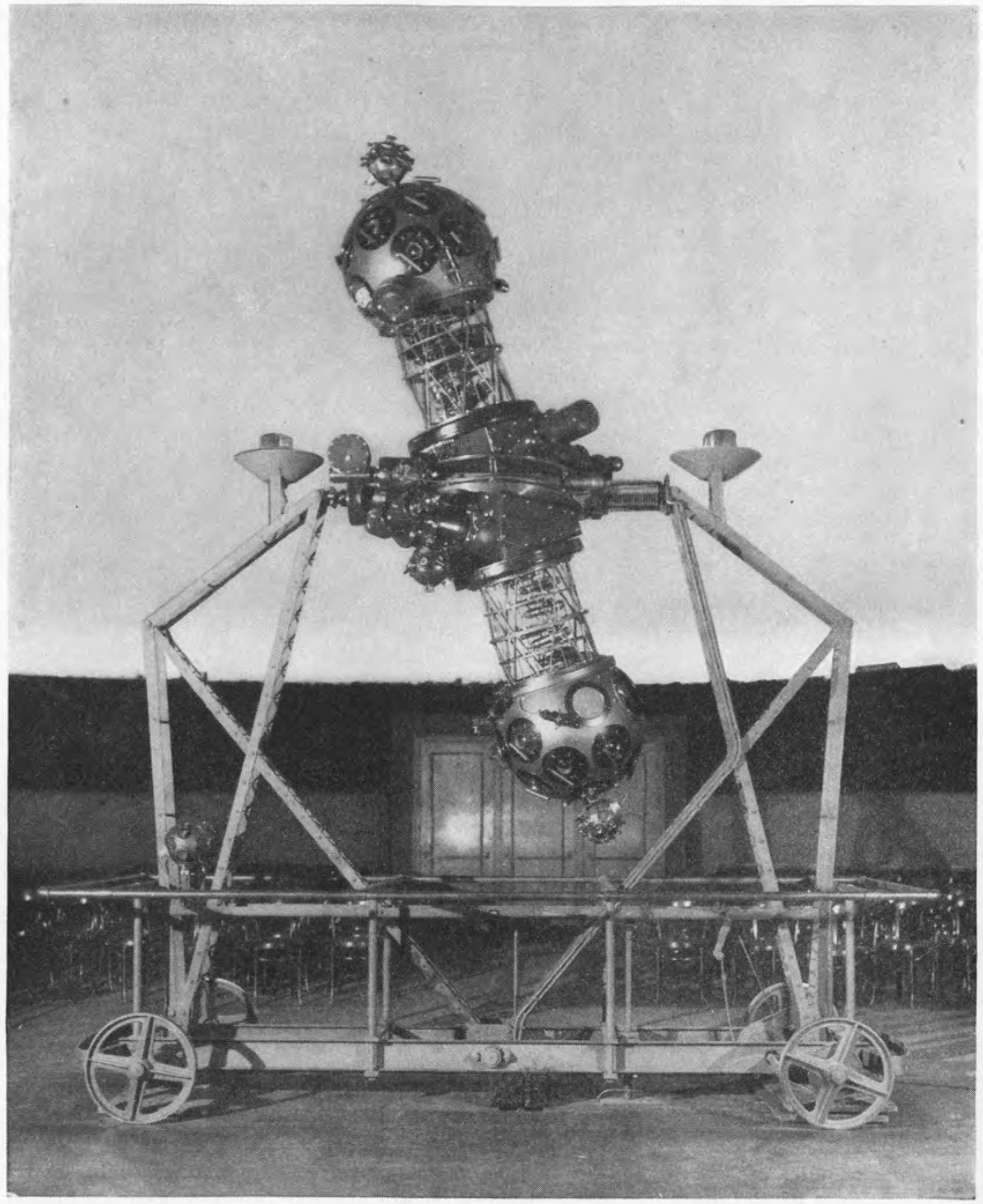


PLATE II. THE PLANETARIUM INSTRUMENT IN THE CHICAGO INSTALLATION.

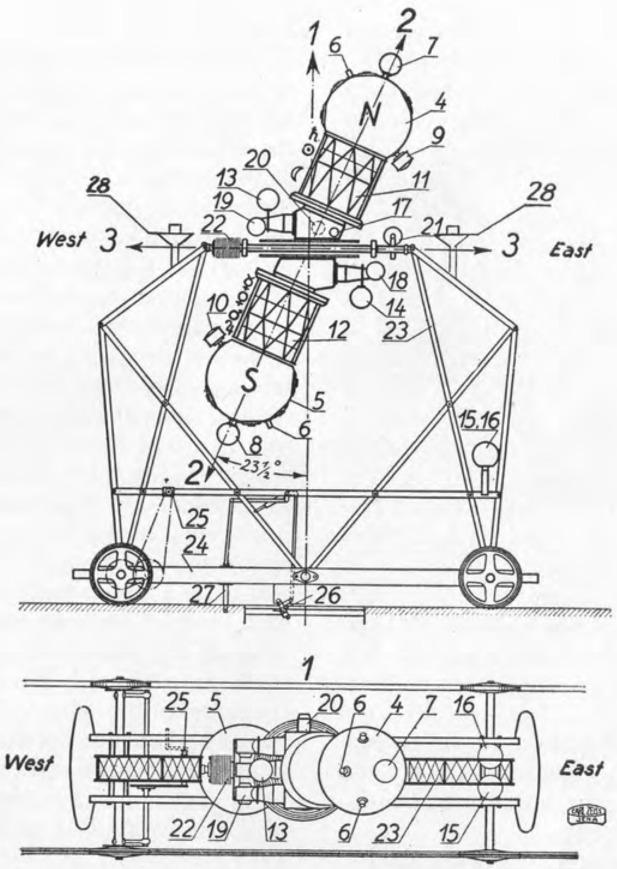


FIG. 4. DIAGRAM OF THE PLANETARIUM INSTRUMENT IN PLAN AND ELEVATION.

1-1—Polar Axis. 2-2—Axis of the ecliptic. 3-3—Horizontal axis extending east and west. The whole projection apparatus may be rotated about this axis, producing the changing aspect of the sky consequent on change of latitude. N, S—Two globes, star projector carriers, on which the 32 projectors for the stars are mounted (4, 5, etc.) N primarily for the northern sky, S for the southern. 6, 6—Projectors for the Magellanic Clouds, Sirius, and typical variable stars. 7, 8—Globes which carry 30 projectors for constellation names. 9, 10—Drum projectors for the Milky Way. 11—Cylindrical frame section containing movable projectors for Saturn, Sun, Moon, Gegenschein, and Zodiacal Light. 12—Cylindrical frame section for Mercury, Venus, Mars, and Jupiter. 13, 14—Two globes, each carrying six projectors to throw the equator, ecliptic, sections of numbered hour circles, and arrows to indicate the poles of rotation. 15, 16—Two globes each carrying two projectors to throw the meridian in the sky. 17—Projector to designate the year. 18—Two motors to drive the instrument about the axis (1-1) for diurnal motion. Used singly they give a day in $1^m 4^s$ or $3^m 12^s$. 19—Three motors for the annual motion, or more properly speaking, the motion of the Sun, Moon, and Planets among the stars. Singly the motors give the year in $5^s.8$, 61^s, and $3^m 3^s$. 20—Motor to drive the instrument about axis (2-2) to produce the precessional motion, the 25,800-year precessional cycle in $1^m 16^s$. 21—Motor to rotate the instrument about the axis (3-3) for change of terrestrial latitude, period $5^m 8^s$. 22—Commutators to transfer circuits from the fixed frame to the movable parts. 23—Fixed frame or pedestal built of thin, steel bars, care being taken to obstruct as little light as possible. 24—The carriage. The whole instrument can be rolled along a track from its central station under the dome by the crank and gears at (25). 26—Conduit for electric wires from the instrument to the control desk. One lever engages with one movement the blades for all circuits. 27—Bolt to define the position of the instrument for use. Only when the instrument is in place for this bolt to be shot can the circuit contacts be made at (26). 28—Lamps which throw light upward for the general illumination of the chamber. They are shielded so that no light comes directly into the eyes of the audience. By rheostats these are dimmed or brightened for dusk or dawn, night or day.

an American orrery by T. H. Barlow made in 1851, exhibited at Paris in 1867, and now at Transylvania College, Lexington, Kentucky. Such mechanical models are common adjuncts to class-room instruction.

In 1912 Dr. Wallace W. Atwood, then Director of the Museum of the Chicago Academy of Sciences, designed a very different instrument which has been called the Atwood Celestial Globe. It is described in the *Bulletin of the Academy,* Vol. 4, No. 2, May 1913. The essential feature is a globe fifteen feet in diameter. Holes of proper size and location are perforated in the sphere to represent the stars. Light thrown on the exterior of the globe shining through the holes, gives the appearance of the starlit sky to the observers standing within. The southern circumpolar region is cut away and from this section the observers enter the globe to stand on a platform inserted through the same opening. The globe may be rotated about the polar axis to reproduce the diurnal motion. This Atwood Globe which has been in daily use since 1913 is the progenitor of the new Zeiss Optical Projector. It differs radically from the mechanical planetaria for it is concerned with the appearances of the sky and in no sense is it a mechanical model to explain these appearances.

The Atwood Globe, however, had a much earlier forerunner, for in 1758 Roger Long, Lowndes's Professor of Astronomy at Cambridge, constructed "an enormous astronomical machine . . . at Pembroke College. It is a hollow sphere, about eighteen feet in diameter, with the polar axis parallel to the mundane axis, upon which it is readily turned by a winch and rack-work; thus it can be made to rotate, while about thirty persons conveniently attend a scientific lecture in the interior and contemplate the orderly march of the constellations painted on the moving concavity above them, the stars being pierced through the metal according to the several magnitudes, so that the light penetrates and each assumes a curious radiated or rather stellated form." [2]

Professor Max Wolf of Heidelberg had something of this sort in mind in his original suggestion to Dr. Oskar von Miller of the Deutsches Museum at München. Von Miller daring to bring the heavens indoors, turned to the firm of Carl Zeiss, Jena, for the execution of the work. The engineers of Carl Zeiss at first worked on the idea of a great rotating perforated globe. "Much experimental construction work was carried out in Jena . . . but no satisfactory solution . . . to create the illusion of the mysterious, silent march of the worlds of Nature . . . was found." It is not surprising that an engineer, Dr. W. Bauersfeld, of this firm, which since its foundation in 1846 has been a leader in the development of optical apparatus, should have evolved the following proposition: "The great sphere shall be fixed, its inner white surface shall serve as the projection surface for many small projectors which shall be placed in the center of the sphere. The reciprocal positions and motions of the little projectors shall be interconnected by suitable driving gears in such manner that the little images of the heavenly bodies, thrown upon the fixed hemisphere, shall represent the stars visible to the naked eye, in position and in motion, just as we are accustomed to see them in the natural clear sky." It took Dr. Bauersfeld and his staff of collaborators and workmen a full five years to demonstrate the practicability of the proposition. No more versatile instrument than that which was evolved was ever invented for exhibiting the phenomena of a given science. Its success is convincing, even inspiring. It fittingly occupies the central place in the Astronomical Museum of Chicago.

[2]Cycle of Celestial Objects, Smyth & Chambers, Oxford 1881, pp. 208–9.

THE OPTICAL PLANETARIUM

In its essential elements the optical planetarium (Plate II) is a composite stereopticon with many projectors throwing images on the interior surface of a great hemispherical dome. It is a very complex instrument for it reproduces the intricate phenomena of the heavens. It shows the naked-eye stars, the Sun, Moon, and planets, all in their proper places for any instant of any year of any century for any terrestrial position. A high order of optical technique, mechanical skill, and astronomical knowledge are merged in its design. It may be best understood by aid of the accompanying diagram (Fig. 4).

At first sight it seems strange that the designer did not make the polar axis coincident with the long axis of the dumb-bell. This would have yielded some simplification in the representation of the stars, but the projectors for the Sun, Moon, and planets would then have had high inclinations to this axis and the driving of them would have entailed greater difficulties. Added difficulty would have been encountered in the representation of the precessional motion.

The starry heavens are produced by a mosaic of thirty-two separate fields. The plan for the partition of the sky for the individual star fields provided for the geometrical projection of the sky on the faces of a regular icosahedron whose twelve corners have been cut away to give a 32-sided solid with twenty regular hexagonal and twelve regular pentagonal faces. Each of

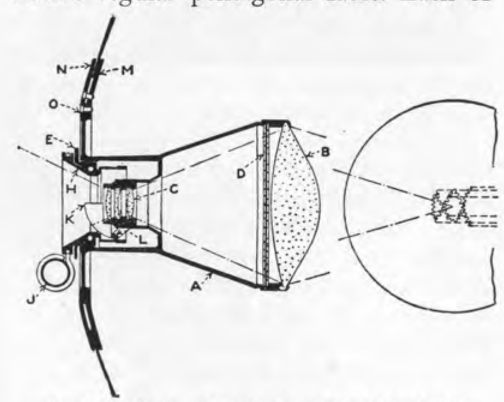


FIG. 5. CROSS-SECTION OF STAR PROJECTOR.

FIG. 6. ASSEMBLED STAR PROJECTOR SHOWING OCCULTING DEVICE.

these thirty-two faces then provides a picture which must be projected optically on the dome. At first, glass lantern slides were tried for the plates but later thin (0.0006 inch) copper plates perforated with holes of sixty-five different sizes to represent stars for the visual magnitudes 1 to 6.5 in steps of 0.1 magnitude were adopted. The difference of brightness for the various magnitudes is then accomplished by the different sizes of the star disks shown on the screen. The images of the fainter stars are scarcely one-eighth inch in diameter but the brightest stars are fully two inches and therefore show decided disks. To the objectionable feature that the stars appear as disks instead of points and also to the distortion of constellations due to out-of-center viewpoint in a celestial sphere of restricted radius, the observer readily adapts himself. The unit star projectors are mounted individually and adjustably on the large spherical carriers. The carriers are twenty-nine inches in diameter of thin sheet brass (0.078 inch) and contain each, centrally placed, a 1000-watt lamp which furnishes the illumination for the star images.

Fig. 5 shows one of the star projectors in diagrammatic form and Fig. 6 assembled.

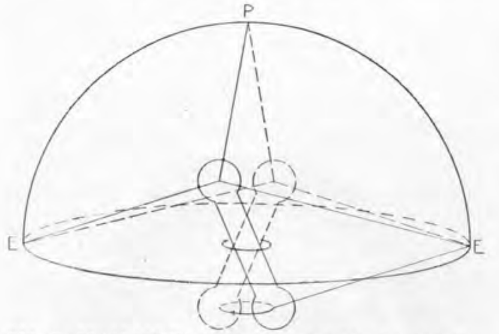


FIG. 7. DIAGRAM TO SHOW THE NEED FOR ALLOWANCE FOR PARALLACTIC DISPLACEMENT IN THE POSITIONS OF STARS ON THE PERFORATED PLATES.

(A) is the container, (B) is the condenser, (D) the perforated plate, (C) the Zeiss Tessar projection lens, Aperture = 2.66 cm, F = 12 cm, (M) and (N) are the adjustment rings and (O) the clamp. Inasmuch as only that part of the sky above the horizon is to be shown, an occulting device is provided for each projector to shut off the light when the lens is pointed below the horizon. This is a spherical sector (K) which serves as a mechanical eyelid, not unlike the device used for dolls which open and close their eyes in appropriate posture. Its axis is mounted in the ring (H) which in turn has a ball-bearing mounting in the race (E). The axis is kept level by the weight (J), a cylinder partially filled with mercury, which provides a delicate sense of level. Moreover, the edge of the shutter (K) is kept parallel to the horizon by the weight (L). The gradual covering of the objectives simulates well the atmospheric absorption near the horizon.

The individual fields, fitted together to give a complete and continuous picture of the sky, are adjusted with respect to each other by moving the projectors within the adjustment rings (M) and (N). This is done once for all when the instrument is erected in the dome. Temporary adjustment marks are provided for the purpose. This adjustment is a matter of great importance and considerable delicacy. No matter how accurately the individual star fields represent the stars within their areas, if they are not in accurate mutual adjustment there will be obvious distortions at the junctions. The position of each perforation in the star plates must be carefully calculated to allow for the distortion of geometrical projection, for optical distortion, and more critically still, for a parallactic displacement that enters because the spherical surfaces of the carriers are not concentric with the dome and also because the axis of diurnal rotation does not pass through the centers of the globes. A star on the equator and one at the pole must be 90° apart on the hemispherical screen but it is readily seen from Fig. 7 that the perforations for them cannot be 90° apart. Neither can two perforations throwing star images to opposite points on the equator be 180° apart on the globes. When it is realized that 9000 stars are represented the amount of preliminary calculation can be appreciated.

On the spherical carriers are mounted also special projectors for the Magellanic Clouds, for Sirius, and on the Chicago instrument, projectors for three typical variable stars, Algol, Mira, and δ Cephei. A separate projector for Sirius is provided that the great brightness might be attained by a brighter disk instead of one of excessive size. The lights for the variables are controlled at will by means of rheostats in

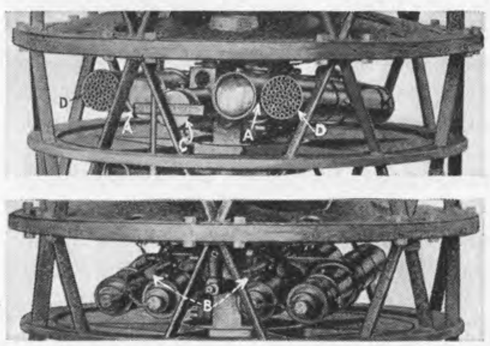


FIG. 8. FRONT AND BACK VIEWS OF THE SOLAR PROJECTOR.

the demonstrator's desk. Each of these special projectors has its own occulting device.

The spherical carriers bear also the cylindrical or drum projectors for the Milky Way. This feature of the sky is shown very realistically. A negative drawing of the Milky Way was prepared producing the different intensities by stippling with fine dots irregularly placed. This drawing was

then photographed on a film. The film is wrapped within a double-walled cylindrical vessel in the center of which is the lamp. By half filling the narrow space between the walls of the vessel with mercury, the occulting of the part of the Milky Way below the horizon is neatly accomplished.

It is not necessary to comment at length on the projectors for constellation names for they operate in the same manner as the star projectors even to the occulters. The names in general fall in vacant parts of the constellations. They may be turned on or off at will. That projector which covers the north pole of the ecliptic shows also the location of the poles of the planetary orbits and the circle described by the pole of rotation as a result of precession, dated to indicate the position of the pole in the different chiliads.

The images of the members of the solar system are thrown on the dome by individual projectors. These are located in the cage-like framework between the globes and the mid-section (Fig. 4). In all cases they are in pairs and of large aperture to minimize the effects of obstruction of the struts of the cages in which they are placed. Optically the planetary projectors are alike except that the images have distinguishing character. Mars is red, Jupiter has belts, Saturn has rings, Mercury and Venus are distinguishable by size. The Sun and Moon offer some optical differences.

The solar projector, of which front and back views are shown in Fig. 8, is complicated by serving a manifold function. With it is combined a device (D) for a halo of diffuse light centered on the Sun which by contrast blots out the fainter neighboring stars and which gives a glow at dawn forewarning of sunrise and at dusk above the hidden Sun. At (C) a series of prisms like steps of a stairway (see also Fig. 14) throws a faint glow along the ecliptic for the Zodiacal Light and at (B) are two small projectors to throw a faint patch of light to the opposition point for the Gegenschein.

The Earth's orbit is an ellipse; therefore neither the Earth's distance from the Sun nor its angular velocity is constant. We are not directly concerned with the variation of the radius vector but if the Sun is to appear at correct celestial longitudes, the variation of angular velocity must be accurately reproduced. Simple circular motion, which mechanically has obvious advantages, cannot be directly employed, for the errors in the Sun's position would be easily perceptible. Fortunately, however, it is possible to use an adaptation of uniform circular motion by placing the Sun eccentrically in the circular orbit, making this eccentricity double that of the ellipse.[3]

In elliptic motion the mean anomaly, expressed in terms of the true anomaly, v, is

$$2\pi\frac{t}{T}=v-2e\sin v+\frac{3}{4}e^2\sin 2v-\frac{1}{3}e^3\sin 3v+\ldots.$$

Similarly, for circular motion about a point placed eccentrically, the relation is

$$2\pi\frac{t'}{T}=v-(e_1-\frac{1}{8}e_1^3)\sin v+\frac{1}{24}e_1^3\sin 3v+\ldots.$$

For small eccentricities the two equations give closely approximate values for motion of the radius vector if $e_1 = 2e$.

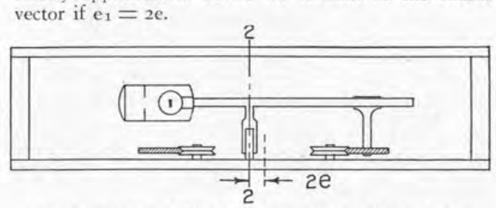


FIG. 9. SCHEMATIC VIEW OF SOLAR PROJECTOR.

Fig. 9 shows the arrangement in schematic form. The solar projector is centered

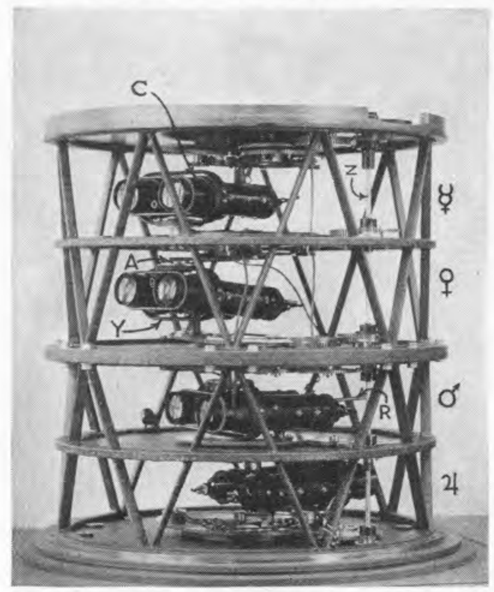


FIG. 10. SOUTHERN SECTION OF THE PLANETARY CAGE.

[3]F. Auerbach. Handbuch der Physikalischen und Technischen Mechanik, 1928, Vol. II, p. 142.

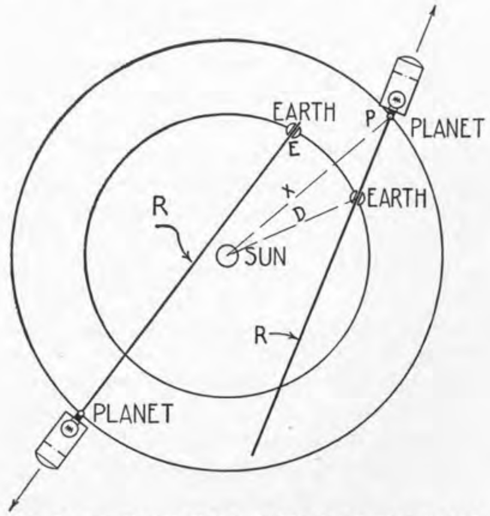


FIG. 11. TO SHOW THE PRINCIPLE OF THE ALIGNMENT OF A PLANETARY PROJECTOR.

on the axis (2-2) of Figs. 4 and 9, and is driven by an eccentrically mounted annulus which in turn is driven by spur gears from the main annual driving shaft (Z) (Fig. 10).

Inasmuch as the solar projectors are north of the plane of the ecliptic they are given a fixed inclination to bring the solar image upon that circle. The projectors for the Gegenschein are tilted similarly toward the opposition point. The brightness of the Sun may be varied by rheostat control but even at its maximum permits the view of the stars and accordingly the Sun's course among them.

Since in the sky we view the moving planets from a moving Earth their apparent motions are compounded of their own and the Earth's. In the planetarium the optical axes of the projectors in all cases and at all times must be directed along lines through the position of the planet and the Earth. All the vicissitudes that the different inclinations, non-commensurable periods, non-uniformity of speed introduce in the sky must be reproduced in the planetarium. Also, since none of these projectors can be in the plane of the ecliptic each must be given a tilt to bring the planet on the ecliptic when it should be at the nodes.

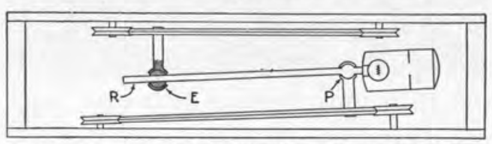


FIG. 12. SCHEMATIC VIEW OF A PLANETARY PROJECTOR.

Each pair of projectors (Fig. 10) firmly bound together by a collar (C) is pivoted in the yoke (Y) free to rock about the long axis of the collar. The yoke (Y) can be rotated about an axis (A). Figs. 11 and 12 show the principle by which the alignment of the projector is maintained in the case of an outer planet. The same principle holds for an inner planet Mercury or Venus with the roles (E) and (P) reversed.

Consider now just one planet. The aligning rod (R) passes through a sliding bearing carried on a universal joint at (E), the position of the Earth. The position of the planet (P) is on the axis (A) on the yoke mentioned above. As the positions of (E) and (P) change and their distance apart changes, the aligning rod (R) slips through the bearing at (E) which rotates and tilts, accommodating itself in all directions. At the same time the collar bearing the projectors tilts in the yoke which the while turns back and forth about the axis (A). In the planetarium the points (E) and (P) are carried on disks on opposite faces of the cage-chambers, one on the floor and the other on the ceiling. The terrestrial disk carrying the point (E) is centered on the axis (2-2) and is perpendicular to it. It is driven at uniform speed from the main planetary driving shaft (Z) by means of suitable reduction gears. A stud mounted on this disk carries the universal slide-bearing (E) which may be raised or lowered to adjust the aligning rod (R) that it will point the projector to the ecliptic at the moments of nodal passages. Moreover, this stud is offset from the axis of the disk an amount (D) proportional to the Earth's distance from the Sun. The planetary disks for Venus, Jupiter, and Saturn, whose orbits have low eccentricities, are essentially like the terrestrial disk. Their centers are slightly offset from (2-2) to partially compensate for eccentricity, with the point (P) on the yoke-axis (A) at a distance (X) from the disk center in the proportion that D/X = ratio of the distances of the Earth and Planet from the Sun. The plane-

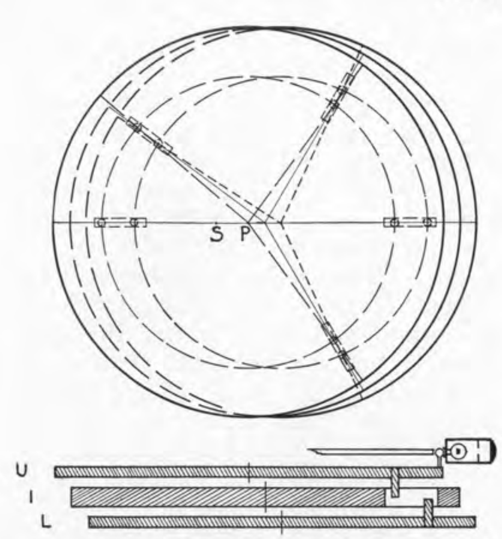


FIG. 13. SCHEMATIC REPRESENTATION IN PLAN AND ELEVATION OF PLANETARY DRIVING DISK FOR ORBIT OF HIGH ECCENTRICITY.

tary disk is inclined to the terrestrial at an angle equal to the inclination of the orbit to the ecliptic. The terrestrial and planetary disks are not borne on central axes but are supported at the rims by three small sheaves. In general this device affords rigidity. It permits the use of fairly light disks without attendant tremors. It is of course apparent that any vibration of the axis of projection produces a greatly multiplied displacement on the dome, nearly a hundredfold.

For Mercury and Mars, where the orbital eccentricities are high (0.2056 and 0.0933) the angular velocity, which varies in the orbit inversely as the square of the radius vector, changes so considerably that a modification of the simple planetary disk was adopted, whereby though still using a combination of crank motions with the initial disk driven at uniform speed, the point (P) moves in a circle and still changes its angular position in close agreement to true anomaly of the elliptic orbit. Three disks are employed. The upper, let us say, carries the axis (A) of the yoke, that is, the point (P). It is centered on the orbit's center, properly offset from (2-2), even as are the simpler planetary disks. The lower disk, which is the one driven from the main driving shaft (Z) is offset from (2-2) in the same direction but by twice the amount. The intermediate disk (I) is centered midway between. These three disks are (U), (I), and (L), in Fig. 13. A pin on the upper side of (L) engages in a slot in (I); also a pin from the lower side of (U) engages in this same slot. When (L) is driven uniformly, a point on the periphery of (U) describes an angular motion about (2-2) in close approximation to the variation of true anomaly. The greatest deviation from true position of Mercury, which is the most critical case, is less than one degree. This deviation is of course not cumulative. This triple planetary disk is tilted to provide for the inclination of the orbit as in the simpler cases.

In the southern cage an element of simplification and mechanical economy is provided by having the terrestrial disks for Mercury and Venus back to back on opposite sides of the separating diaphragm between their chambers. The diaphragm is perforated and the disks are then one body with but one set of driving gears from the main shaft (Z). A similar economy is found for Mars and Jupiter. In the northern cage the annual drive of the Sun is carried similarly into the cage for Saturn and also into the lunar cage where it is applied to the gear train of the lunar phase meniscus to be described later.

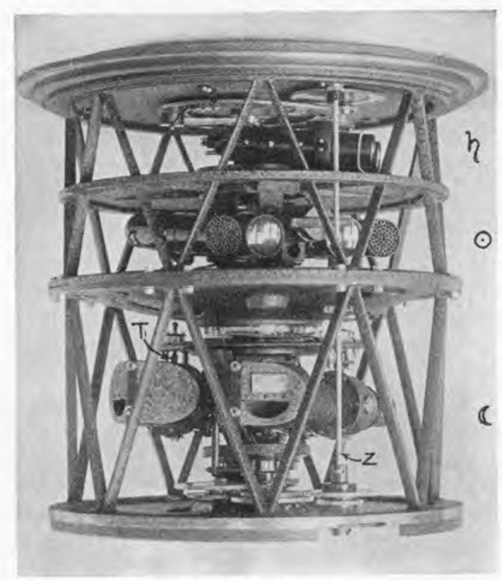


FIG. 14. NORTHERN CAGE CONTAINING THE PROJECTORS FOR THE MOON, THE SUN, AND SATURN.

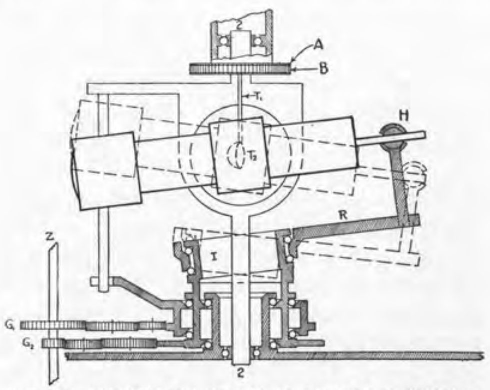


FIG. 15. SCHEMATIC DRAWING OF LUNAR PROJECTOR SHOWING THE LOCATION OF THE PHASE MENISCUS AND THE DEVICE FOR ACCOMPLISHING THE REGRESSION OF THE NODES.

As stated in an early paragraph, Huygens discovered the principle of continued fractions in designing his mechanical planetarium in 1682. Since that time this principle has been employed in all similar gear problems where it is desired to approximate the ratio of incommensurable periods. Application of the principle to Mercury yields, after some adjustment, for the number of teeth of the gears

$$(45\times66\times86)/(65\times91\times104)=0.41520905$$

This figure when divided by 1/10, the ratio of speed of the terrestrial disk to the main planetary shaft (Z), gives 4.1520905 which is a close approximation to the true ratio of the Earth's and Mercury's sidereal periods, 4.15209106: 1. The teeth numbers are large enough to give smooth motion and yet not so large as to require large gears or, to avoid that, small teeth. The error in the ratio is so small that the accumulated residual will amount to one degree only after five thousand planetarium years. For the other planets an accuracy of the same order is attained.

The projector for the Moon (Fig. 14) provides the only perturbation that is represented, the 18.5995-year period of regression of the nodes. The lunar projector carriage is centered on the axis (2-2) and is driven about this axis in a period of one sidereal month. Under the projector and centered also on (2-2) is an inclined plane member (I) (Fig. 15) which controls the inclination, 5°9′. If for a moment we neglect the regression of the nodes the lunar projector would rotate about (2-2) changing its tilt by rocking in the bearing perpendicular to (2-2) and to the line of projection, being constrained so to do because the guide rod (R) is attached to a plane rolling on ball bearings on the inclined plane (I). In one rotation the Moon would make its migration above and below the ecliptic and would always reach its nodes at the same longitudes and come to the points of maximum latitude among the same stars. If now the gears which make the monthly revolution are disengaged and the inclined plane member is set to rotating in its equivalent period of 18.5995 years, the inclination of the lunar projector would slowly change until in the half-period the projector would be pointing as far above the ecliptic as nine years earlier it had pointed below. The bearing on the guide rod (H) must be a universal slide bearing. Both the lunar projector and the inclined block are driven from the main planetary shaft (Z) through independent gears trains (G_1) and (G_2). With the monthly and nodal regression motions both in operation, the Moon will go through its configurations and stations with the nodal points slowly moving westward along the ecliptic. This is a very necessary feature of the instrument for without it the planetarium would be wholly useless for reproduction of eclipse configurations.

Another interesting mechanical and optical device provides that the Moon appear

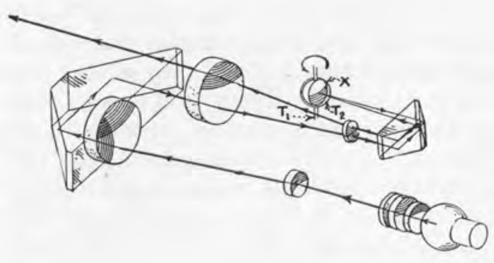


FIG. 16. PATH OF THE BEAM THROUGH THE LUNAR PROJECTOR.

in phase appropriate to its configuration. In Fig. 16 the path of the beam from the lamp may be easily followed through lenses and totally reflecting prisms until it strikes a

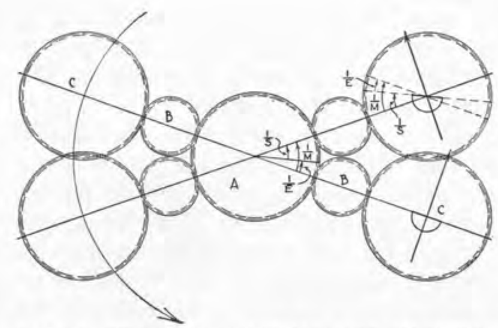


FIG. 17. DEVICE TO DRIVE THE MENISCUS FOR LUNAR PHASES WITH THE SYNODIC PERIOD.

small metallic concave mirror (X). Projection of the image of this mirror when fully illuminated gives full moon; fractional illumination yields the lesser phases. Pivoted on an axis (T_1) aligned with the reflecting face of the mirror and perpendicular to the ecliptic is a closely fitting hemispherical meniscus or cup (T_2) which rotates on its axis in a period of one synodic month. Since the edge of this hemispherical shell will project always as an ellipse, it will properly represent the terminator.

As noted previously the annual motion of the Sun is transmitted directly into the lunar cage. The central axis carrying the solar projector and aligned on (2-2) protrudes into the lunar chamber and there carries a spur gear (A) (Figs. 15 and 17). Meshed with this gear through idlers (B, B), mounted on the lunar projector carrier are others (C, C) having the same number of teeth as (A), their axes carrying in prolongation the axes of the occulting cups which, as noted above, are therefore perpendicular to the ecliptic. The design has placed the cups in prolongation of the axes about which the lunar projectors oscillate perpendicularly to the ecliptic so that they stand always at a fixed distance from the top of the cage. If the gear (A) (Figs. 15 and 17) from the solar projector were fixed instead of in motion the lunar drive carrying the projectors through an angle $1/M$ would rotate the cups a like amount and in one rotation, that is, in a sidereal month, would rotate the cups through 360°. But, because (A) is rotating with a period of one year it automatically and with the utmost simplicity lengthens the period to one synodic month, for in one day it would turn through an angle $1/E$ thereby retarding (C) by a like amount. The relation $1/M - 1/E = 1/S$, where E is the year, M the sidereal month, and S the synodic period, is maintained. The horns of the crescent Moon point along the ecliptic and not exactly away from the Sun but the error is not perceptible except when the Moon is very near the Sun and only then when near its greatest celestial latitude. But since the Moon is scarcely to be seen within one day of conjunction the malposition of the terminator will in general escape notice.

The main planetary driving shaft (Z) in its two sections provides that the solar, lunar, and planetary motions take place in perfect synchronization for the gears are all interlocked. The terrestrial disks all rotate with one-tenth the speed of the shaft (Z), the planetary disks in strict proportion.

The locations of the sets of projectors which throw the principal astronomical reference circles on the dome are indicated on the diagram of the instrument (Fig. 4). The projectors for the equator and ecliptic (13, 14) must of course move with the instrument and the circles which they project travel with the stars, being displaced only by precessional motion. By a series of lenses full circles are projected on the sky, the ecliptic graduated in daily dated stations of the Sun, the equator graduated to indicate right ascension. The projectors for the meridian (15, 16), on the contrary, are fixed on the standard. As our horizon is always with us, fixed in the chamber, so are the zenith and meridian. Illuminated letters, N, E, S, W, faint of course so as not to be obtrusive, stand along the horizon at the cardinal points. At each point is also the letter of the opposite point for as one travels on a meridian over the pole all directions reverse. These graduated reference circles are useful for instruction in the coordinate systems and their interrelation, and even for the solution of simple problems in practical astronomy and navigation.

The over-all length of the great dumbbell is twelve feet. The center of motion which is in the plane of the horizon is 9.81

feet above the floor. The weight of the movable parts approaches a ton. The support for it is built of steel in lattice-work fashion of the thinnest allowable members consistent with the demand for freedom from vibration or oscillation, just as in the planetary cages the struts are thin and placed edge-on to the line of projection that the obstruction shall be as slight as possible.

There are four distinct types of motion: that for change of latitude; the diurnal motion; the interlocked motions of the Sun, Moon, and planets; and the precessional motion.

The first of these is wholly independent of the others. The motor drives the whole movable part of the instrument about the axis (3-3) (Fig. 4) perpendicular to the meridian, thereby changing the inclination of the polar axis (1-1) and producing a change in the aspect of the sky like that resulting from change of latitude. The arrow-head markers for the poles move along the graduated meridian and permit the latitude to be read directly by the polar

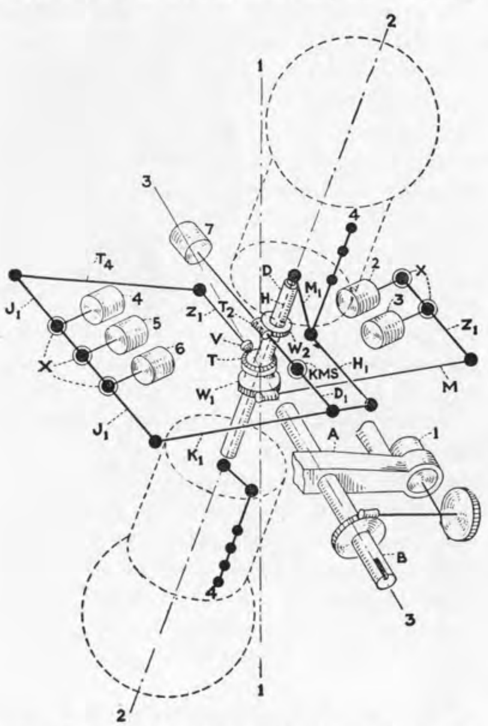


FIG. 18. COMPLETE DESIGN OF MOTOR DRIVE IN SCHEMATIC FORM.

altitude. The alternative method of reading the zenith distance of the intersection of meridian and equator is also available. The period for the 360° circuit is $5^m\ 8^s$.

There are two motors for the diurnal motion which rotate the instrument about the axis (1-1) (Fig. 4) in periods for the sidereal day of $3^m\ 12^s$ or $1^m\ 4^s$. These motors can be operated together or opposed, yielding periods of 48^s or $1^m\ 36^s$. A recently installed attachment provides for diurnal speeds of one-third those stated, days three times as long.

The synchronized solar, lunar, and planetary motions, commonly referred to as the annual motions, take place within the body of the instrument. There are three motors which in the Chicago instrument used singly operate at the rates of a year in $3^m\ 3^s$, 61^s, and $5^s.8$. They may be run in any combination forward or backward. The shortest possible year with all in either forward or backward motion is $5^s.1$.

The remaining motion is that about the axis (2-2). This reproduces the precession of the equinoxes, for it changes the direction in which the ecliptic faces with respect to the equator and sends their points of intersection, the equinoxes, in westward motion. The stars move parallel to the ecliptic changing right ascension, declination, and celestial longitude, but with celestial latitude unchanging. In nature the precessional cycle requires 25,800 years; in the planetarium $1^m\ 16^s$. As the equinoxes move, the pointer at the equatorial pole moves about the pole of the ecliptic in a circle of radius equal to the obliquity of the ecliptic. As noted earlier this circle graduated in chiliads is thrown on the dome by a projector in (7) (Fig. 4).

The diurnal, annual, and precessional motions are not wholly independent but are interconnected in some operations mandatorily but not necessarily reciprocally. Thus the operation of the diurnal motion carries with it the commensurate annual and precessional motions, but neither the annual nor precessional carries the corresponding diurnal. The operation of the annual motion requires the proportional precessional change but the reverse is not true. So in general, the motions which in nature are

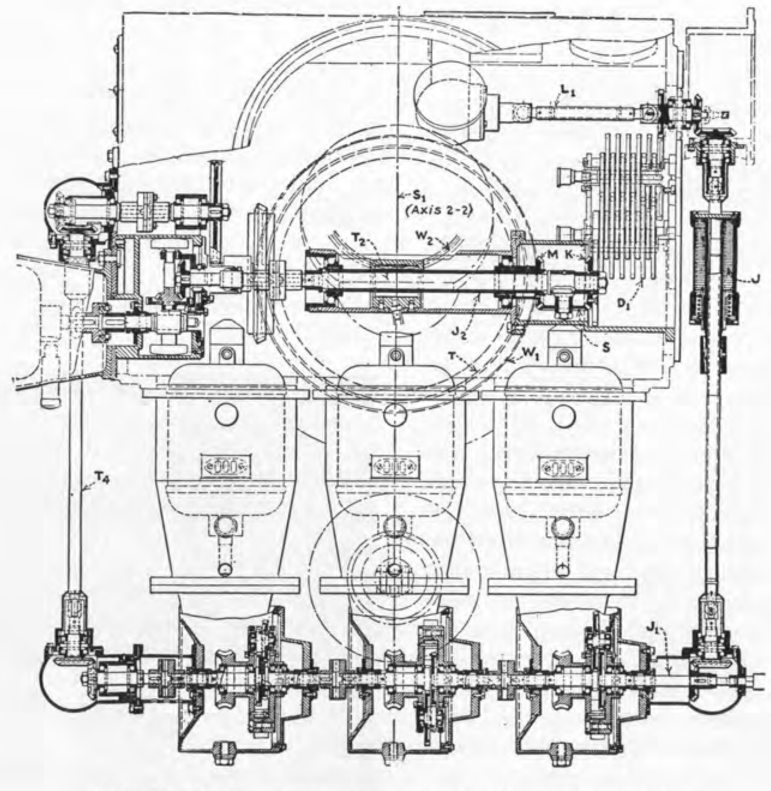


FIG. 19. DETAIL OF THE ANNUAL AND PRECESSIONAL DRIVES.

of short period carry with them in the planetarium operation those of longer period and this of course either backward or forward in time but the reciprocal action does not hold. This does not imply that the daily motion may not be operated when the annual is on, or when the precessional is on, nor that the annual may not be used when the precession is in operation, nor that the independent precessional or annual motions may not be superposed on the proportional automatic ones. Various combinations are possible but the automatic connections are as stated. Some combinations give very curious results. Since diurnal and annual speeds of nearly equal periods are provided it is possible by using the two together to have perpetual noonday. Also, with opposed precessional and annual motions one may have perpetual spring. Fig. 18 shows the general course of transmission of the motions and Fig. 19 some interesting details of the transmission.

It is not necessary to elaborate on the change of latitude drive. As noted before, this motion is entirely independent. Its method of application from the motor (1) through two worm gears is apparent in Fig. 18.

The three annual motion motors (4, 5, 6) (Fig. 18) transmit by (J_1 K_1 H_1) to the planetary shaft in the north cage and by (M_1) and a shaft through the perforated precessional axis (2-2) to the planetary shaft in the south cage. The planetary shaft is here number (4, 4). Heretofore it has been designated (Z).

At (D_1) a shaft is taken from (K_1) to transfer the annual motion to the precessional axis for proportional motion. A multiple reduction involving a 3000-fold step-down is shown in Fig. 19 at (D_1). Thirteen gears are involved between (K_1) and the bevel gear (K). The bevel gear (M) is mounted on the head of the precessional driving worm shaft which turns the worm wheel (W_2) and thereby rotates the instrument about the axis (2-2). The worm shaft

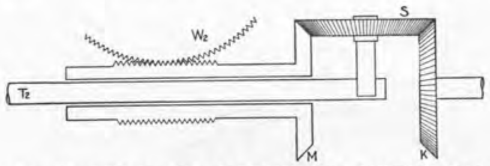


FIG. 20. DETAIL FOR PRECESSIONAL MOTION AND THE ANNUAL INCREMENT THEREOF.

is perforated and the shaft (T_2) from the precession motor (7) passes through it (Fig. 20). The motion from the annual train and from the precession motor (7) are both applied to the gear (M) through the intermediate bevel gear (S), the axis of which is a pin through the shaft (T_2). If the annual motion is running, the gear (K) will drive (S) and thereby (M) and the worm (W_2) in the proper ratio to the year. The axis of (S) will remain fixed in direction. If, however, the precessional motor (7) is running, the shaft (T_2) will turn and with it of course the axis of the gear (S), entailing motion of (K) or (M) or both. But since (K) is practically locked by the manifold gear reduction it stands fast and (M) is driven. The annual motors then deliver automatically the attendant precession but the reverse does not apply.

The diurnal motors (2) and (3) (or 18 in Fig. 4) transmit their motions through the shafts (Z_1) and (M) to a worm (W_1) mounted as an integral part of the cradle which carries the whole instrument in its bearing on the axis (3-3). With either or both of these motors in operation the instrument is driven about the polar axis (1-1). The bevel gear (T) turns with (W_1) and through the pinion (V) and shafts (Z_1, T_4) drives the main annual motion shaft (J_1) and so through the whole train for the proportional increment of annual motion and even the precessional motion.

From the rapidly turning annual motion motor to the creeping precession requires extraordinary gear reduction. There are 25,800 years in the precessional cycle. If the motor makes 1600 RPM and if the year required exactly one minute, the reduction would be 41,280,000 to 1. For the $5^s.8$ annual motion this would be 3,990,400 to 1. The greatest reduction is from the slowest diurnal motion by the circuitous route through the annual motion to precession, where the reduction, providing the motors run at 1600 RPM, would be 48,248,064,000 to 1.

The wiring for the electric circuits is another interesting feature of the instrument. The lamps in the great globes for the star projectors are 110 volts, 1000 watts. For the other multiple projectors for constellation names, circles, etc., they are 30 volts, 100 watts; and for Sun, Moon, planets, Sirius, variable stars, etc., they are 6 volts, 10 watts. The commutators on axis (3-3)

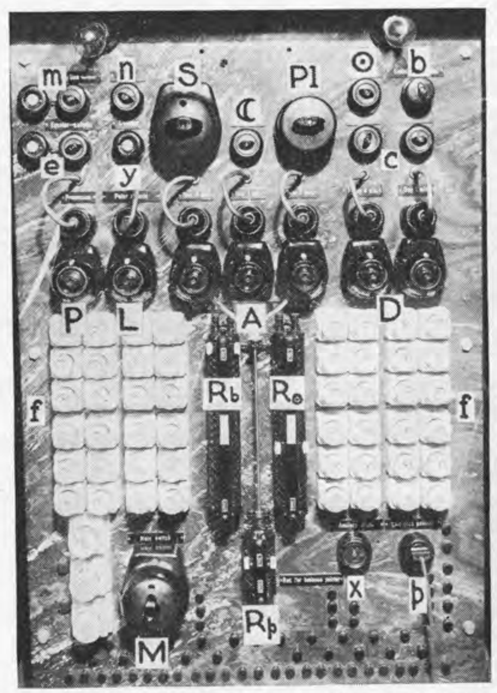


FIG. 21. CONTROL BOARD AT THE DEMONSTRATOR'S DESK, WHICH IS ENCLOSED TO CONFINE ITS FAINT ILLUMINATION.

m—Meridian. A push button for momentary presentation (extinguishes on release) and switch for longer showing. e—Equator, ecliptic, and sections of hour circles. Button and switch. y—A button for the year counter. n—Constellation names. S—The stars. ☾—Moon. Pl—Planets. ☉—Sun. c—Cardinal points. b—Switch for control-board lights. The lamps are seen at the top of the board. Ordinarily these are hooded. P—Precessional motion. L—Change of latitude. A—Annual motion, slow at the left, intermediate in the center, and fast at the right. D—Diurnal motions, slow at the left and fast at the right. Rb—Rheostat for adjustment of control-board illumination, the lights (b). R☉—Rheostat to control the brightness of the Sun. Rp—Rheostat to control the brightness of the optical pointer. p—Plug for optical pointer. x—Extra circuit. f—Fuse plugs. M—Master switch.

may be seen in Fig. 4 at (22). There are thirty rings for the distribution from the pedestal to the movable parts of the instrument at this stage. There are other distribution rings on the great plate in the equatorial plane and also on either side of this in the plane of the ecliptic. They provide unbroken circuits with entire freedom of motion about the axes (1-1), (2-2), and (3-3). For the planets there are individual rings with sliding spring contacts. The electric circuits are led down the frame in small tubes and make contacts with the cable leading to the control board by a many bladed knife switch under the standard at (26) (Fig. 4).

The control board (Fig. 21) at first glance seems fairly complex but it is logically arranged and sufficient mastery to enable the demonstrator to operate it in the dark or with dim light is soon acquired. Considerable experience and practice are needed, however, before the demonstrator can without hesitation make the correct contacts. If from inexperience he must divert attention from the thought of his lecture to consider the operation of the switchboard, his discourse is interrupted or perhaps incoherent. A novice should not drive an automobile in city traffic. Fortunately in the planetarium no damage can result from turning the wrong switch except that to the speaker's complacency. It is a matter of chagrin to prepare an audience for the approaching trip to the pole and find instead the equinox moving among the stars with swiftly rolling centuries. An obvious solution is to have a trained operator and free the lecturer from the responsibility. But more freedom, more elasticity, more spontaneity are available if the demonstrator manipulates the controls.

The master switch for connecting all circuits is at the bottom of the board (M) (Fig. 21). All switches for projectors are in the top section of the board; all for motions are in the row (P, L, A, D) across the upper center of the board.

By reversing the plugs above the seven switches (P, L, A, D), the directions of motion are reversed. The seven motors under instant control by the several switches may be operated in as many different ways as there are possible combinations, having in mind that any or all of them may be arrested or reversed. Mathematically there are 2187 possible combinations, including the one when all circuits are dead. The vast majority of combinations serve no logical or illustrative purpose. For example the use of all seven in any possible combination of direct or reverse would produce an almost meaningless phantasmagoria. The combinations actually used are comparatively few, less than two score. Certain interesting combinations to give perpetual noonday or eternal spring have been previously cited. Just as certain combinations are of interest so also certain sequences of motion are of value; for example, the change of latitude to bring the pole to the zenith to be followed by diurnal motion to show the movement of the stars on the "parallel sphere."

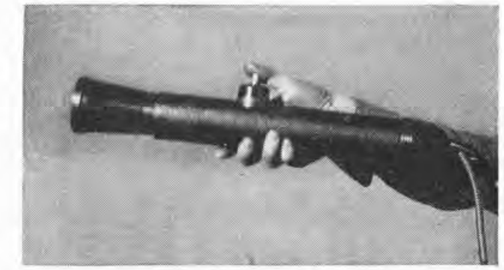


FIG. 22. THE OPTICAL POINTER.

Ready to the hand of the demonstrator is an optical pointer (Fig. 22). It is plugged into the switchboard at (p). Its brightness may be controlled by (Rp). It is a focusing lamp which throws an image of an arrow on the dome. As it is held in the hand any point of interest can be indicated. Care must be exercised to use it sparingly, to move it slowly, to hold it steadily on the object, to extinguish it when it has served its purpose. Rapid motion of this arrow or unsteady holding or excessive brightness is annoying.

The remaining features of the control station are the switches and rheostats for the lights (28) (Fig. 4) which furnish the general illumination of the chamber, and the rheostats to produce the change of brilliancy of typical variable stars. This feature of variable stars is new with the Chicago instrument.

Near the demonstrator's desk there is an auxiliary projector for showing lantern slides. These may be flashed on the dome as in any ordinary illustrated lecture. In pointing out the Great Cluster in Hercules, for example, a picture of it might be projected on the dome to show its appearance in a great telescope. For such purpose the lantern is of great value.

In the Adler Planetarium certain pieces of accessory apparatus have been developed for use with the stereopticon to reproduce the phenomena of eclipses, meteoric showers, aurora, etc.

The planetarium affords means for illustration of a great variety of astronomical phenomena, too many to present in a single lecture. At the Adler Planetarium twelve topics have been selected which serve fairly well as vehicles to show the various possibilities of the instrument. Normally, the topics are rotated, each one serving for a month.

- January—Winter Constellations of the Home Sky.
- February—Time and Place.
- March—The Calendar.
- April—The Moon and Its Motions.
- May—The Way of the Planets.
- June—The Midnight Sun; the Heavens at the North Pole.
- July—Summer Constellations of the Home Sky.
- August—The Southern Sky; the Southern Cross.
- September—The Seasons; the Annual Journey of the Sun.
- October—The Great Precessional Cycle.
- November—Objects of Special Interest in the Sky.
- December—Architecture of the Heavens.

In devising a program it is obvious that the method of presentation must differ in several respects from that of the university class room. For the audience there are no intellectual prerequisites; there is mixture of age and interest through wide range; there are some making their initial visits, others who have been frequently in attendance. There can be, therefore, no strictly formulated progression. Each lecture must be measurably self-contained. Some features are common to all demonstrations for each includes a brief description of the instrument and exhibits the phenomena of diurnal and annual motions. Beyond this, emphasis is placed on items particularly associated with the topic for the month. What these must be is obvious in most cases but even so, careful consideration is necessary if repetition is to be avoided and discourse and sequence of events are to fit in orderly and natural fashion.

January and July are devoted to constellation study. Methods and history of nomenclature are discussed. The ancient star groups and the principal stars are pointed out; where they may be seen at different hours at different seasons. The lantern lends its aid with slides of the constellation figures, slides of paintings or sculptures portraying the old stories of mythology and of temples oriented to certain stars, and slides of interesting astronomical objects in the constellations. No Chicago youth can in later years cry out with Carlyle: "Why did not someone teach me the constellations and make me at home in the starry heavens?"

Time and Place brings emphasis to the systems of reference circles and coördinates. The circles are projected on the dome. Solar time, sidereal time and their relation; the inequality of apparent solar days; the equation of time and need of mean time can be exhibited very simply. The change in aspect of the sky with change of latitude may be seen; the altitude of the pole or meridian zenith distance of the equator can be read directly.

The Calendar continues the previous topic with the consideration of the adjustment of the incommensurable units of day and year. An interesting feature in this lecture is the demonstration of the Metonic Cycle, the equality of 235 months to nineteen years.

The Moon and Its Motions includes an explanation of the phases, the reason for great meridian altitude of the full Moon of winter and *vice versa,* the orbital inclination, the Harvest Moon, the regression of the nodes, eclipse of the Sun and Moon. For the exhibition of eclipses special apparatus has been devised and constructed.

In *The Way of the Planets* the phenomena of planetary motions are considered more thoroughly. The rapid annual motions are here of greatest value. The looping of the apparent paths in the sky, the retrograde motions, critical or multiple conjunctions are exhibited very vividly. It is beautiful to see the planets describing their rhythmic arabesques among the stars. The triple conjunction of Jupiter and Saturn in 1940–41 is nicely shown. The agreement of the dates with those yielded by calculation demonstrates the usefulness of the instrument for approximate computation.

The Midnight Sun of course requires that the Sun be at the Summer solstice and that the observer be on the arctic circle or still farther north if the solar declination is less. The place and time for the Sun's setting are observed, first in the latitude of Chicago, then farther north until the phenomenon of the Midnight Sun is revealed. The hour of sunset can be read by the projected coördinates, its place can be noted by the buildings of the Chicago skyline cut in silhouette along the horizon. At the pole the circling of the Sun, planets and stars along almucantars, with the pole star near the zenith, shows the parallel sphere. The Sun sets at the autumnal equinox and in the arctic night the aurora borealis appears. For this a simple piece of apparatus (also designed here) serves admirably.

The Southern Sky: the Southern Cross is treated in much the same manner as the lectures on constellation study. On the way south a pause is made at the equator to show the right sphere.

The Seasons: the Annual Journey of the Sun is one of the most effective lectures. The course of the Sun along the ecliptic, the low short arc of the Sun in the winter day (counting the hours), the long night, and reciprocal conditions in summer, give convincing explanation of summer's heat and winter's cold. The changing meridian altitude of the Sun through the year is neatly shown by running the diurnal and annual motions together, using the nearly equal periods, so adjusted as to give perpetual noonday, itself an interesting phenomenon.

The Great Precessional Cycle is the topic perhaps of greatest interest to astronomers because the change of the sky from precession in a human lifetime is so slight that acquaintance with it, while of great interest, is generally encountered as an annoying consideration in dealing with star positions. It is very strange to see the swift motion of the stars in circles parallel to the ecliptic, to see the equinox moving among them and the pole reeling about the pole of the ecliptic. It is curious to see the sky of 3000 B.C. with Thuban (Alpha Draconis) as the pole star, with the Vernal Equinox in Taurus, the Southern Cross appearing above the Chicago horizon; or leaping far into the future, 14000 A.D., to see Vega as the pole star, the Vernal Equinox in Virgo, Sagittarius high in the sky and holding the summer solstitial point, Alpha Ursae Minoris setting, the Southern Cross again appearing, and Orion far from the Equator, at upper culmination only half above the horizon. An interesting variation can be accomplished by running the precession against the synchronized annual motion, thereby attaining perpetual spring or eternal summer. The lecturer with simple apparatus shows the relationship of astronomical precession to the familiar gyroscopic motion of spinning objects here on Earth.

Objects of Special Interest in the Sky takes up in sequence the different kinds of objects: proper motion stars, double stars, giant and dwarf stars, variables, multiple stars, clusters, nebulae, pointing them out, showing slides of them and about them. The rheostat control of the variables is used very effectively here. In this lecture (partly because it is given in November) a meteoric shower is projected realistically on the screen with the radiant in Leo. This is produced by a device which has been made in the instrument shop of this institution.

The *Architecture of the Heavens* may serve either as an introduction to the series or a summary of the whole. The method of star counts to demonstrate galactic concentration is illustrated. The Milky Way, so beautifully portrayed, takes on its true significance. By putting the nodes of the galactic plane at the east and west points and then changing latitude, it is possible to bring first one pole of the galaxy then the other to the zenith. When this is done our solar system is shown to be well to the north of the median plane.

It is possible to vary these lectures for any purpose at will. For example, on several occasions Officers of the U. S. Navy stationed in the vicinity of Chicago, Naval Reserve Officers, the Naval R.O.T.C. Unit of Northwestern University, and Army Officers of the Air Service, have attended special demonstrations for instruction in the astronomical phases of navigation, or perhaps it were better to say, demonstrations to illustrate the applicability of the planetarium for such instruction. While the contents of the lectures may be varied *ad libitum* the twelve topics outlined above have been adopted for the scheduled demonstrations.

The minimum schedule of demonstrations of the Planetarium offers lectures each week-day at eleven o'clock in the morning and at three in the afternoon. In addition there are lectures at eight in the evening on Tuesdays and Fridays; on Sunday afternoons lectures are given at three and four. In summer this program is expanded by additional lectures in the afternoons and evenings. During the Century of Progress Exposition an hourly schedule of demonstrations will be in effect.

The visitors come to see a stirring spectacle, the heavens brought within the confines of museum walls. Not a trivial plaything, a mimic aping firmament, but the heavens portrayed in great dignity and splendor, dynamic, inspiring, in a way that dispels the mystery but retains the majesty, a revelation of the sky so beautiful that with Milton one may say

> ". . . . fragrant the fertile Earth
> After soft showers, and sweet the coming on
> Of grateful evening mild; then silent night
> With this her solemn bird and this fair Moon
> And then the gems of heaven, her starry train."

PLATE III. "THE PHILOSOPHER READING A LECTURE ON THE ORRERY."

An engraving made in 1768 from a painting by Joseph Wright. Presented to Mr. Adler for the Museum by Dr. J. Wirth of Frankfurt am Main.

THE ASTRONOMICAL MUSEUM

What might one expect to find in an astronomical museum? Certainly apparatus to show the fundamental laws so far as they can be so illustrated,—laws of dynamics, optics, spectroscopy, photometry, etc.; apparatus to show methods of observing; collections of instruments to show their development to modern forms; portrayal of results of observations so far as they can be brought to reveal the nature of the Sun, Moon, Planets, Comets, Stars, and Nebulae, the scale and architecture of stellar systems.

This museum is particularly fortunate in the possession of a superb collection of antique instruments. Some four hundred years ago the Strozzi family of Florence began a collection of scientific instruments, gathering and preserving things of worthy achievement. About forty years ago this collection passed into the hands of Raoul Heilbronner in Paris, after the War to Ant. W. M. Mensing in Amsterdam, and from him to the Chicago museum. It contains an unexcelled collection of astrolabes, nocturnals, armillae, globes, sundials, early telescopes, etc., by the most skilful craftsmen of the fifteenth, sixteenth, seventeenth, and eighteenth centuries. The items are marvellous not only for the learning and mechanical skill they display but for the beauty of workmanship. This collection of about six hundred pieces, to which generous friends have made recent additions, forms the background of the Museum.

It is remarkable that so many choice instruments have survived intact the shocks of the many years. The astonishment increases when one follows the quest of modern instruments which have figured prominently in scientific progress. So many have fallen victim to what Dr. Gunther has so charitably characterized as the "adaptive ingenuity of the younger scientists."

Heilbronner had added some pieces to the collection while it was in his hands. Like accretions took place after the acquisition by Mensing, approximately thirty per cent in number of pieces. Mr. Ant. W. M. Mensing is a dealer and connoisseur in art treasures with a wide and detailed knowledge of old books, matters pertaining to navigation and exploration, and makers of maps, globes, and ancient instruments. Mensing made a fine contribution to the literature on ancient instruments in the preparation and publication of a detailed, descriptive, analytical, richly illustrated catalogue. In the preparation of this work he was fortunate in having the assistance of Max Engelmann of the Mathematisch-Physikalischen Salon of Dresden, whom Dr. Bassermann-Jordan[4] characterizes as "ein so vollkommenen und vielseitigen Kenner." The notes of this catalogue have been of inestimable value in the study of the various pieces described and for an extension of the study to the uncatalogued items acquired also from Mensing and to pieces added later from other sources. From this catalogue it is at once apparent that the collection in its special field is of extraordinary character, worthy to be compared with those of the Ashmolean Museum at Oxford, the Science Museum in South Kensington, London, the Conservatoire National des Arts et Métiers in Paris, or the Deutsches Museum in München, or with that gem-like collection in the jewel-box setting of the Mathematisch-Physikalischer Salon in Dresden. The installation of the Mensing Collection here puts this institution in an enviable position among scientific museums.

The limiting dates of the items are 1479 and 1800. For that period the work of many of the foremost instrument makers is represented by original pieces. From Germany such names as Cajetanus, Ducher, Hahn, Hartmann, Heiden, J. Martin, Purman, Reinmann, Schniep, Schissler, Stark, Trechsler, Willebrand. From France: Bion, Chapotot, Chardin, Chesnon, DeMongenet, DuBois, Danfrie, Grandjean de Fouchy, Langlois, LeMaire, Lepere, Marquart, Meurand, Martin, Martinot, Pigeon, Passement, Sevin. From Italy: Blondeau, Bos, Ferrari, Giamin,

[4] Die Uhrmacherkunst, Halle (Saale) 12 Dec. 1924, p. 776.

Lusuerg, Mariani, Merula, Ravilius, Rodella, Stefani, Vulparia. From Holland: Bonius, Blaeuw, van Ceulen, Isenbroek, Oller. From Belgium: Arsenius, Coignet, D'Amery, Rechter. From Sweden: Sauter. From Bohemia: Habermel. From England: Bennett, Blagrave, Butterfield (worked mostly in Paris), Cole, Deane, Dollond, Marshall, B. Martin, Masig, Nairne.

Just as the illustrious instrument makers are represented, so also are the principal centers: Augsburg, Cassel, Danzig, Dresden, Frankfurt, Göttingen, Leipzig, München, Nürnberg, Ulm, Prag, Pressburg, Wien, Aix les Bains, Blois, Clermont, Paris, Strasbourg, Florence, Milan, Naples, Padua, Rome, Urbino, Venice, Delft, Haag, Haarlem, Antwerp, Brussels, Louvain, Stockholm, London.

It is a collection of such character that Professor Bassermann-Jordan in a review of the Catalogue wrote, "Wenn die Sammlung Mensing auf den Markt kommen sollte, so werden die deutschen Museen sehr darauf zu achten haben, dass die wichtigsten deutschen Stücke Deutschland erhalten bleiben." (If the Mensing Collection should be placed on the market the German museums must have care that the most important German pieces remain in Germany.) The collection was offered to sale only in its entirety: through the generosity of Mr. Max Adler it came to Chicago intact. Those who with reluctance see such masterpieces of technical skill and artistic merit depart from their shores may be assured that this institution recognizes equally with them the solemn obligation to preserve and cherish the best work of past generations, that our respect for the knowledge and achievements of ancient masters may be enhanced and that the course of development of instrumental design may be revealed, both of these factors to serve as an inspiration for progress. Moreover, on seeing these treasures one's mind turns irresistibly, and with growing admiration, to contemplation of the culture of the cities where they were made.

Today the skilful instrument maker is the essential right hand of the investigator and this has been the case since first the observer took to instrumental aid in his search for greater precision and wider horizons. Then, even as now, both investigator and instrument designer and maker are often found in one individual. In our day we find the investigator keen in the design and development of new equipment. We may mention Rowland and the grating, Michelson with the echelon and interferometer, Nichols and the radiometer, Langley and the bolometer, Talcott and the zenith telescope, Herschel and his telescopes, Hale and Deslandres with the spectroheliograph. And so it was in the past. Blaeuw was the greatest cartographer of his time. Bion's "Traite de la Construction et des principaux Usages des Instruments de Mathematique" went through many editions, was translated into many languages. Galileo, maker of telescopes, founded modern mechanics and the experimental method in physics. Regnier Gemma (Gemma Frisius), professor of medicine in Louvain, suggested the method of triangulation in survey operations. Georg Hartmann, mathematician and theologian, was Vicar of St. Sebaldus in Nürnberg. Heiden was professor of mathematics at St. Agidien.

FIG. 23. A.M. 392. A MECHANICAL PLANETARIUM BY PIETER ISENBROEK, HAARLEM, 1738.

The fundamental problems of practical astronomy are the determination of time, geographical position, direction, star positions, motions of the Sun, Moon, and planets. Most of the pieces of the Mensing Collection bear directly on these problems for purposes of observation, recording, or explanation. There are some pieces not strictly astronomical but they give variety to the collection, illustrate the scientific instrument maker's skill in the most artistic period, show the reciprocal influences of instrument construction in astronomy and allied fields. Even the grim business of war, especially during the Thirty Years War (1618–48), with the intense development of artillery, fortifications, topographical mapping, etc., contributes clinometers, geodetic instruments, various scales, calipers, range finders, etc. Nicolas Bion in the preface to one edition of his work mentions the dual applicability of the various instruments in peace and war.

The instruments will be listed and described under various classifications but many of them are composite and might equally well fit into any one of two or more groups.

Mechanical Planetaria. The Museum has three mechanical planetaria of early date which are noteworthy. The first, A.M. 392 (Fig. 23), was constructed by Pieter Isenbroek in 1737–8 and is therefore among the earliest. It stands 78 cm high and is 81 cm in diameter. The stand of walnut is very handsomely designed and finished. The celestial circle for the Tropic of Cancer bears the inscription "Door Pieter Isenbroek is dit Planetarium Uitgevonden den 5 Octob. 1737; en door den zelve Volmaakt primo Zeptembr, 1738. En Verbeetert Door Jan Pereste Haarlem 1793." It was rather badly shaken in its long voyage but with some attention to the clock-work it may even now be kept in operation.

The second, A.M. 391 (Fig. 24), is by Benjamin Martin (b. Worplesdon, Surrey in 1704, d. London 1781). Martin was a prolific writer and an instrument maker of skill and ingenuity. Mr. R. S. Whipple of the Cambridge Instrument Co., himself the possessor of an admirable collection of antique instruments, in an address[5] for the Royal Institution 23 May 1930 characterizes Martin as "the first outstanding English instrument maker in the eighteenth century." Among Martin's publications is a tract of date 1771 "The Description and Use of an Orrery of a New Construction."

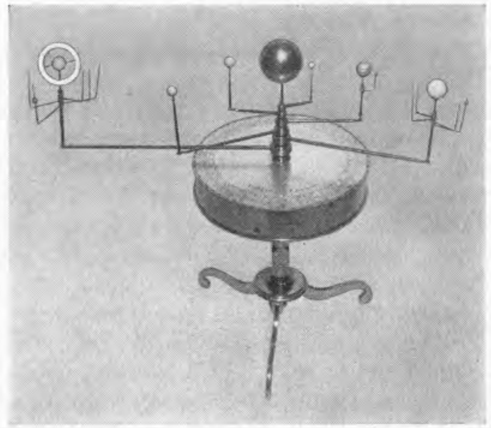


FIG. 24. A.M. 391. A MECHANICAL PLANETARIUM BY BENJAMIN MARTIN, LONDON, C. 1780.

The third is a Tellurion Clock, (Fig. 25), exhibited as a loan from Mrs. V. G. Malmstrom-Klaas of Chicago. It was constructed by Count Nils Filip Gyldenstolke with the aid of the watchmaker J. J. Sauter in Stockholm in the years 1795-1805. It is of brass, steel, and silver, height 22 cm. The globe is by R. B. Bate, London 1809. It gives the position of the Earth and Moon day by day, gives the hour, the day, the month. It is of superb workmanship. (See Fig. 48, A.M. 302, a Sauter ring dial.)

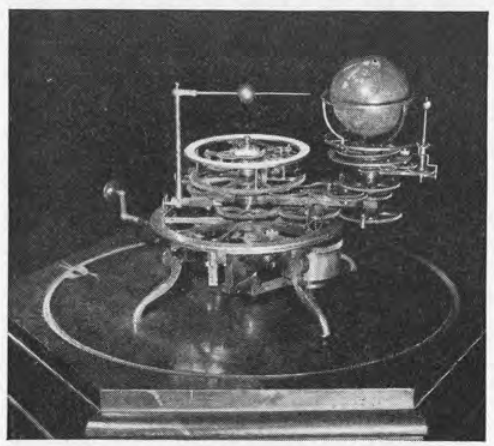


FIG. 25. A TELLURION CLOCK BY COUNT NILS FILIP GYLDENSTOLKE AND J. J. SAUTER, STOCKHOLM, 1795–1805.

[5] *Science N. S.*, **72**, p. 209, 29 Aug. 1930.

Besides these antique planetaria, a modern electrically-driven planetarium by the Eastern Science Supply Company is exhibited and has been in almost constant operation for two years. The Museum acknowledges also the gift from the makers of a hand-driven Trippensee planetarium.

Globes. It may seem curious that the idea of a spherical Earth came to acceptance far later than the idea of the celestial sphere for the former is a fact, the latter a convenient fiction. Yet the stars and constellations were pictured on a globe centuries earlier than the construction of the first terrestrial globe. The nightly wheeling of the heavens brought the stars to recurrent appearance. The circumpolars directed the minds of the observant to the idea of the celestial sphere with the stars studded thereon. On the other hand the general acceptance of the globular Earth came only with the age of great explorations.

FIG. 26. A.M. 440. A CELESTIAL GLOBE BY WILLEM JANSZON BLAEUW, AMSTERDAM, 1638. DIAMETER 67 CM.

The earliest celestial globe extant is the marble Atlante Farnese preserved in the Royal Museum of Naples. Its date can be roughly estimated by the location of the equinoxes and seems to be about 300 B.C. It may even be by Eudoxus of Cnidos (409-356 B.C.) whose globe was described by the Cilician Aratus (c. 270 B.C.) in his poem "Phaenomena." Contrast the date of this early globe with that of the oldest extant terrestrial globe, that of Martin Behaim of the year 1492, the so-called Erdapfel, of the German Museum in Nürnberg.

The Behaim globe does not embody the first idea of an Earth globe for Crates of Mallos (d. 146 B.C.) made a terrestrial globe about 150 B.C. and Strabo (c. 63 B.C.-24 A.D.) refers to this in writing, "Whoever would represent the real Earth as real as possible by artificial means, should make a sphere like that of Crates." But this early idea was long lost to view.

Willem (Guilielmus) Janszon Blaeuw of Amsterdam (1571-1638), pupil and friend of Tycho Brahe, among the most distinguished of the long line of Dutch cartographers, is represented in the Mensing Collection by a great celestial globe, diameter 67 cm, engraved for the equinox 1640. (A.M. 440, Fig. 26). This globe came originally from the old Rubens House in Antwerp. It is a brilliant example in excellent preservation. Stevenson[6] mentions but one other of this size and date and that is in the Royal Library, Madrid.

The Arabs, preservers of learning, are represented by a beautiful bronze globe, diameter 174 mm, delicately engraved, the brighter stars inlaid in silver, with careful regard to relative brightness. (A.M. 14, Fig. 27). Inscriptions giving the star names re-

[6] Stevenson, Terrestrial and Celestial Globes, New Haven, 1921.

FIG. 27. A.M. 14. AN ARABIC GLOBE OF ABOUT 1650. BRASS. STARS INLAID IN SILVER. DIAMETER 174 MM.

semble in modified form those of the globe of Mohammed ben Muyid el—'Ordhi 1279 in Dresden. Other inscriptions have not yet been deciphered. From the location of the equinoxes the date appears to be about 1650.

Two beautiful silver globes, A.M. 12 and 15 (Fig. 28), engraved in low relief, each 58 mm in diameter, at first glance seem to form a pair. But judging by the pedestal and supporting figure (Herme) the celestial globe is of earlier design, from the middle of the sixteenth century. On the terrestrial globe the continents are well formed thus placing the date in the middle of the seventeenth century. The artist has engraved ships and creatures of the land and deep on the surface. He has drawn somewhat on his imagination in the matter of giraffes in South America, and crocodiles in Canada. Both globes are probably of South German origin.

In Stevenson's interesting volumes it is stated that the only known globe by Christian Heiden (1527-1576) is in Dresden.[7]

A.M. 16 closely resembles the work of this master. It will be examined carefully to see if it may gratify Stevenson's "pleasurable hope" that his published list might serve to bring to light other globes not included, by adding one by Heiden.

Two silver globes, one signed DeMongenet, gifts to the Museum from Dr. Harry S. Gradle of Chicago, are extensions to the Stevenson list. The Terrestrial Globe bears no maker's name but the Celestial has two inscriptions:

ELABORABAT	EXIMO VIRO
FRANCISCUS	D. GABRIĖ
DE MONGENET	LI A
ANNO	TIESBACH
1605	(Mark)

Since the globes are of identical size, 86.5 mm, and design of mounting they are evidently a pair by the same cartographer. The known work of François DeMongenet of Vesoul and Besançon is of the years 1541 to 1552. The dates on the mountings are in both old and new calendars; therefore they are later than 1582. There can be no error in reading the date 1605; moreover the equinox places the date in that neighborhood, perhaps a little earlier. François DeMongenet died before 1592. These globes

A.M. 12. A.M. 15.
FIG. 28. TWO SILVER GLOBES. DIAMETERS 58 MM. SOUTH GERMAN OF SEVENTEENTH AND SIXTEENTH CENTURIES.

[7]Stevenson, Terrestrial and Celestial Globes, Vol. I, p. 157 (The size given in the text should be corrected to 72 mm.)

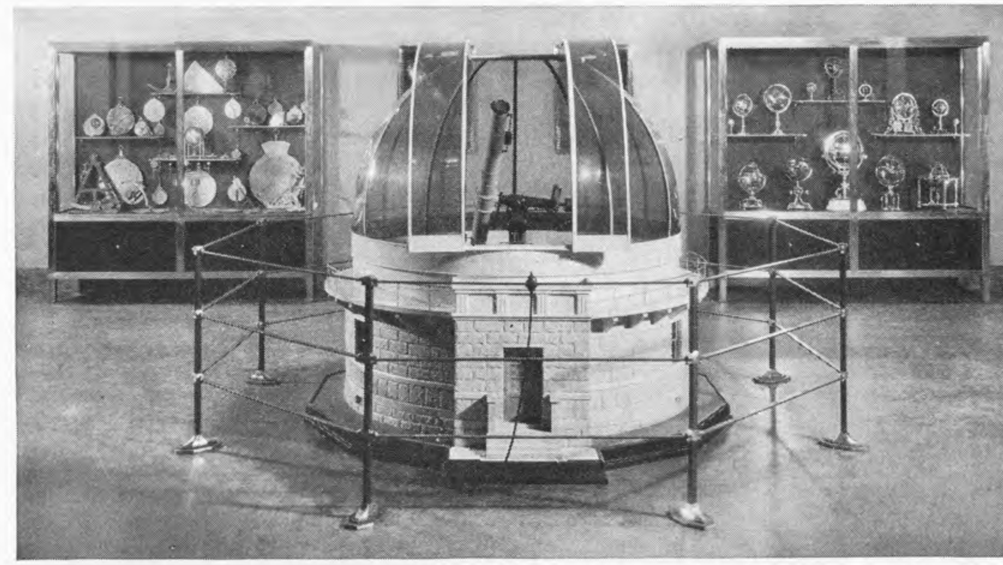


FIG. 29. NORTH HALL SHOWING MODEL OBSERVATORY AND CABINETS OF ARMILLAE AND ASTROLABES.

are probably by a later engraver either a descendant or a copyist. The meagerness of information on DeMongenet and his career illustrates very well the difficulty of tracing various instrument makers. Also it exemplifies the word of Disraeli that: "Posterity is a most limited assembly. Those gentlemen who reach posterity are not much more numerous than the planets."

The Museum contains several other globes. An undated and unsigned celestial globe (A.M. 485) of silver finish, diameter 117 mm, ecliptically mounted. The location of the equinoxes fixes the date at c. 1500. This is confirmed by the March 12 date of the equinox on the mounting. It bears two pairs of letters NE and OC. A pair by Cary 1806 and 1835; a celestial globe from Weimar of date 1837, a gift of Mr. G. H. Jones of Chicago from the library of his father-in-law, Elias Colbert; and lastly, a celestial globe of date 1930 from Rand McNally.

Armillae. On the earliest celestial globes the systems of astronomical reference circles were inscribed. Diurnal circles, the equator, meridians, and the ecliptic appear on the Atlante Farnese. From these it is an easy stride to the armillary sphere (from armilla, a bracelet) in the midst of which the Earth or solar system might be placed. Ptolemy (c. 100-170 A.D.) in the Syntaxis, or Almagest, describes the method of its construction and use. The Armillary Sphere may serve to represent the reference circles and their relation to the Earth, may serve for the transformation of coördinates, and to determine the actual positions of celestial objects and geographical position. Before the invention of the telescope the armillary sphere vied with the astrolabe and quadrant as the principal instrument of observation.

The collection contains thirteen armillae, each of great interest and artistically wrought. The cabinet where they are displayed is shown in Fig. 29.

Six are signed and dated:

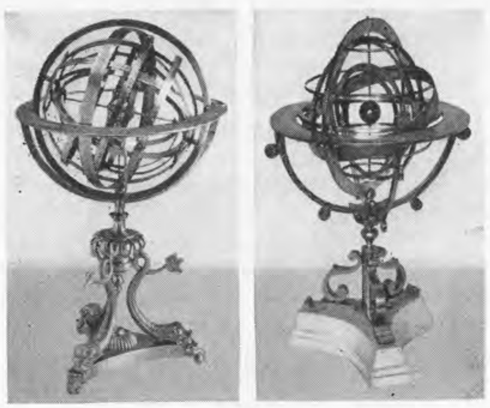
- A.M. 1 Gualterus Arsenius, Louvain 1562 Brass
- A.M. 2 Alex Ravilius, 1542 Brass
- A.M. 4 Hironimus Vulparia, Florence 1582 Bronze
- A.M. 5 Michael Coignet, Antwerp 1591 Brass
- A.M. 8 Fran. Aldinus, 1660 Iron
- A.M. 9 Eile Christian Högh Danicus Brass

In Fig. 30 to the left is the sphere by Ravilius, A.M. 2. All numbers and letters are stamped into the metal. It is inscribed "Io. Thomae Manfredo MDXLII Alex Ravilius F." The support may be of later date, height 470 mm. To the right is an unsigned sphere, A.M. 7, a French or Italian work which stands 670 mm high. There are separate rings for the Sun and Moon. On the legs of the support is inscribed "Cabinet Du Roy Versailles." If this piece was made for the king at Versailles it cannot be earlier than 1627 for in that year the chateau was started, and probably not earlier than 1661 when additions were made. Mansart built the two wings, the chapel, the Galerie des Glaces in 1678. In 1682 Louis XIV took up residence there. The inscription on the instrument may of course be of later date than its construction. While these two armillae are fairly representative, A.M. 1 by Arsenius and A.M. 9 inscribed "Eile Christian Högh Danicus fecit" are of finer workmanship. The first, of the year 1562, shows several stars on small arms projecting from the celestial circles reminding one of the Rete of an astrolabe, many of which were made by Arsenius. It shows also the Earth in the center with the continents in rather crude form. Sir Francis Drake's voyage up the west coast of America came in 1577. Tasman (1603-59) came even later. The Danish sphere is of the seventeenth century. While the continents are more accurately delineated, the peninsula of Lower California is still represented as an island.

Astrolabes. The name astrolabe [αστρον — star, λαμβανειν (λαβειν) — to take] has been applied to a great variety of instruments from a planisphere to an armillary sphere. Here the meaning will be restricted to the flat or planispheric astrolabe described by Messahalla and by Chaucer or by Gemma Frisius or Blagrave.[8] In the commoner form, the essential features are two stereographic projections on the plane of the celestial equator or the meridian, one of the sky or universal sphere bearing the stars and the ecliptic for the Sun's position; the other of the local sphere with vertical circles and almucantars. Due to the Earth's rotation the local sphere and celestial sphere revolve with respect to each other, comparison of coördinates in the two systems providing means for the solution of various problems of practical astronomy.

In the astrolabe the projection of the sky is rotated about the pole; the relations between the projected systems reproduce their relationships of the sky and provide means for almost instantaneous solution of the spherical triangle, Zenith-Pole-Star. In addition there is a rule or alidade with sights for observing the altitude of Sun or stars. In general the instrument is provided with several projections of local spheres applicable for various latitudes. These are called tablets and are contained in fixed position in the outer receptacle called the Mother. The rim of the Mother is engraved for hour angles to be used in connection with the Rete and in degrees for altitude determinations. The tablet in use is on top and immediately under the Rete (from Reticulum, net) or Ankabut, a pierced metal plate, filigree, on which the universal sphere is engraved. The number of stars varies with the size and delicacy of the work. The Rete is rotated about a central pin representing the pole; Rete and tablets and alidade are held on the pin by a wedge called the Horse.

In use the astrolabe is suspended from a ring held on the observer's thumb, the face of the instrument is in the plane of the vertical circle of the Sun or star, the alidade is pointed to the object and the altitude is read on the divided rim of the Mother. With the altitude read, the object on the Rete is brought to the observed almucantar and thereby local and celestial spheres are in adjustment for that moment. The positions of the Sun and all stars can be read at once; the altitudes, azimuths, hour angles, the time,—all read directly.



A.M. 2. A.M. 7.
FIG. 30. ARMILLAE BY RAVILIUS 1542 AND BY AN UNKNOWN MAKER.

[8] R. T. Gunther, Early Science in Oxford V, Oxford. 1929. See also, C. F. Jenkin, The Astrolabe, Oxford, 1925.

The astrolabe is variously ascribed to Hipparchus of Bithynia (c. 150 B.C.), to Apollonius of Perga (c. 240 B.C.), and to others. Hipparchus invented the stereographic projection and used also the armillary sphere. From these two ideas the flat astrolabe was derived, whether by Hipparchus himself, or in India, Persia, or Arabia, is not known. The Arabs certainly appreciated it, preserved, and perfected it, a "Mathematical Jewel." It was not until the latter part of the fifteenth century that it was simplified for use on ship board sailing in various latitudes. Though every great ship during the sixteenth and seventeenth centuries must have been provided with such instruments few have survived the buffeting of time and tide. The deep sea or the bottoms of quiet harbors where lie the hulks of old ships must be their resting places. The astrolabe gave way to the octant and sextant.

It seems curious in our day to learn that Geoffrey Chaucer directed his description of the astrolabe to his son Lowys (Lewis) at age of ten years. It is consoling to know that the great poet put the Latin text into English conceding the Latin treatises too difficult and moreover containing "conclusions that will not in all things perform their promises." Children must have been precocious in those days. But perhaps this quality has carried on and may have been as rare then as now. One is reminded of the verse by the genial Turner linking ancient and modern times.

"A tiny but precocious babe
Was playing with an astrolabe
Her younger brother did prefer
A large interferometer."

The cabinet containing the astrolabes is shown in Fig. 29. There are thirty astrolabes in the collection with perhaps six or eight related instruments. Of the thirty, nineteen are of European construction, nine oriental, and one has both Turkish and French inscriptions. One small oriental astrolabe of primitive form is here on loan by Mr. John Rau of Chicago. The inscriptions on the oriental instruments have not yet been deciphered but the locations of the equinox place them in the sixteenth century. Eight of the European pieces are signed.

- A.M. 21 Bernardini Zabei, Padova 1559, 120 mm
- A.M. 22 Georgius Hartmann, Nürnberg 1540, 140 mm
- A.M. 23 Gualterus Arscenius, Lauanii (Louvain) 1558, 395 mm
- A.M. 24 Gualterus Arscenius, Lauanii 1564, 340 mm
- A.M. 31 Ludovicus Martinot, Agendici (Sens) 1598, 265 mm
- A.M. 33A Ioannes Bos (Roma) 1597, 125 mm
- A.M. 463 P. Sevin, Paris 1682
- A.M. 464 C. Emmanuel, Paris

Of these names Zabeus, Martinot, Bos, Sevin, Emmanuel are not included in the early list of names noted by Gunther,[9] but the first three appear in his later work, "The Astrolabes of the World,"[10] where they are noted as belonging to the Mensing Collection without mention, however, of their transfer to Chicago.

None of the four astrolabes shown in Figs. 31, 32, 33, 34, are of known authorship though the oriental dials may perhaps bear signatures. Two of them are represented both in front and reverse. A.M. 36 (Fig. 31), diameter 150 mm, shows the almucantars at six-degree intervals. This astrolabe is provided with five tablets. A.M. 41 (Fig. 32), diameter 133 mm, is handsomely engraved with patterns of flowers and vines. Almucantars are at three-degree intervals. There are four silver tablets making it adaptable to eight different latitudes.

A.M. 33 (Fig. 33) presents a different type of projection, like that described as the Astrolabio Malcotij in the translation of Regnier Gemma's, De Astrolabo (1556), a small volume "Astrolabiorum" published in Bologna in 1610, like the Saphea of Arzachel. This particular instrument is unusually large, having a diameter of 475 mm.

[9] Gunther, Early Science in Oxford II, Oxford, 1922, p. 219.

[10] Oxford University Press, 1932.

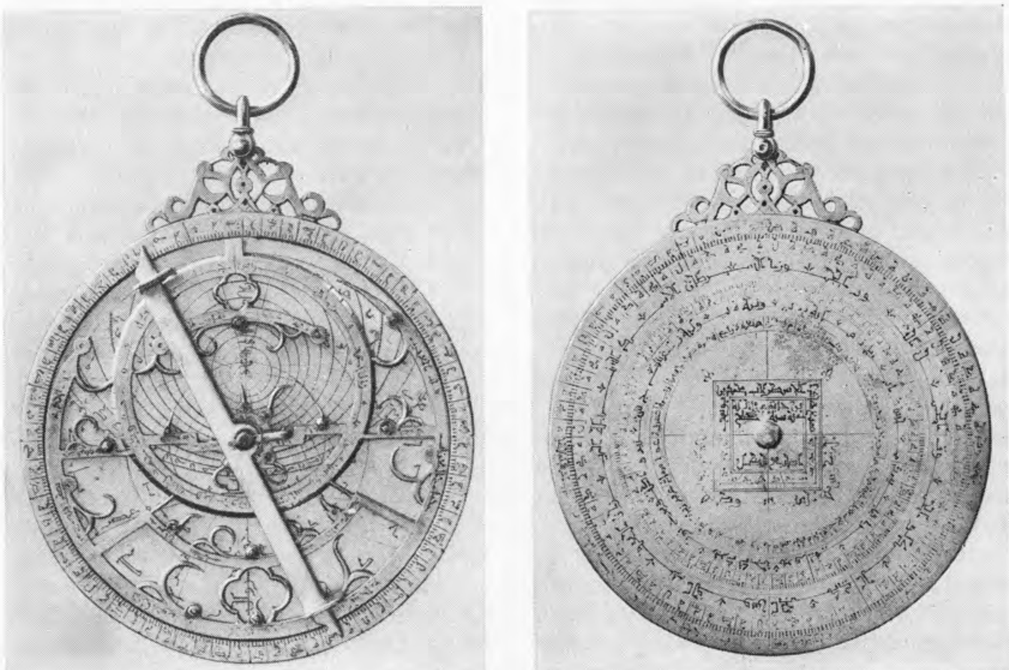


FIG. 31. A.M. 36. AN ORIENTAL ASTROLABE.

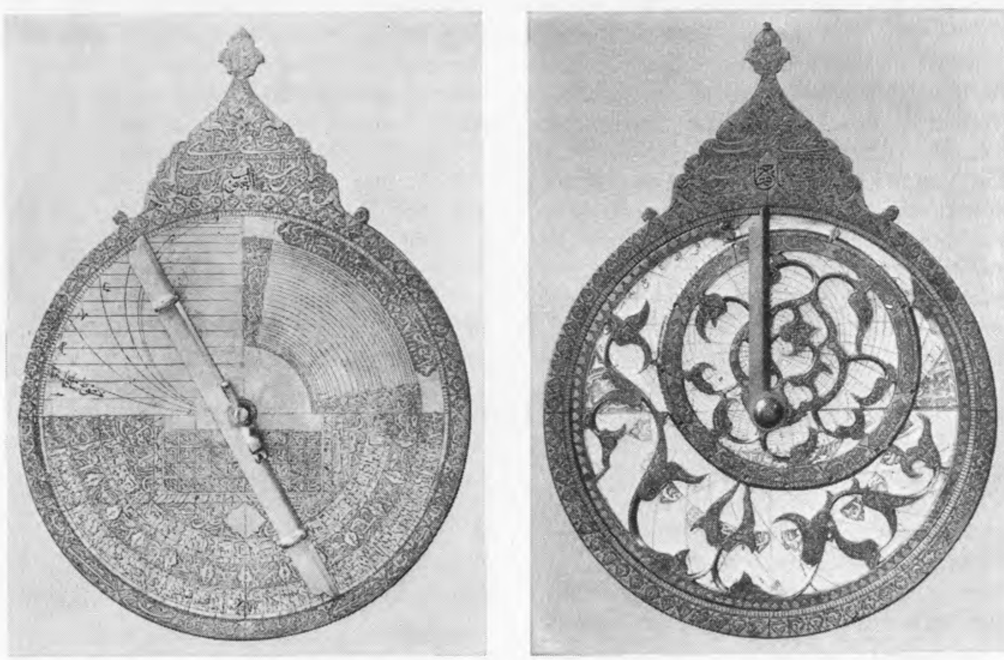


FIG. 32. A.M. 41. AN ORIENTAL ASTROLABE.

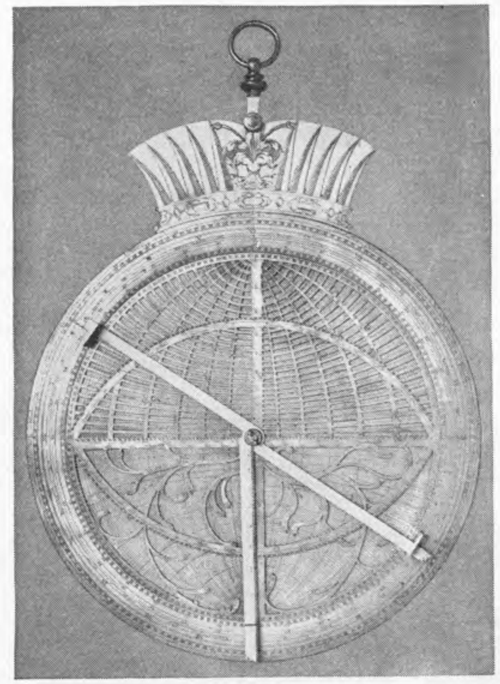


FIG. 33. A.M. 33. A LARGE ENGLISH ASTROLABE. DIAMETER 475 MM.

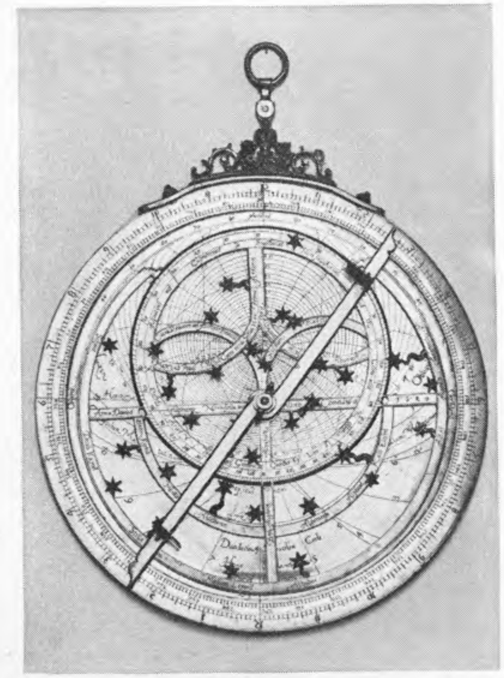


FIG. 34. A.M. 34. AN ASTROLABE IN COPPER. OF THE YEAR 1620.

The inscriptions are in Latin and English. It is undoubtedly of English origin. Dr. Gunther suggests John Blagrave as a probable maker.[11] If so, its date is prior to 1611 for in that year he died. The equinox is given as March 21; therefore the instrument is later than 1582.

Gunther indicates that Habermel, renowned as maker of instruments for Tycho Brahe, constructed an astrolabe for the Strozzi family. An unusual piece in that it is made of copper, and though unsigned, resembles the work of Habermel is present in this collection through the hands of the Strozzi. Engelmann notes "Vermuthlich Werkstatt des Erasmus Habermehl, Prag." From his shop perhaps but not by Habermel for the piece bears the date 1620 and shows the comet of 1618. Habermel died in 1606. This astrolabe, A.M. 34 (Fig. 34), is unique in showing the positions of the "Nova Stella 1600" (P Cygni) and Kepler's "Nova Stella A1604."

As the planisphere is the basis of the astrolabe it is not out of place to mention here a large tilt-top table from the library of Professor H. H. Turner of Oxford, whose rhyme on the astrolabe was quoted above. The table top (diameter 108cm) has a most exquisitely inlaid planisphere. The top is of satin wood, the stars are brass inlay, the lines connecting the principal stars of the constellations and marking the hour circles, equator, and ecliptic are inlaid maple strips as fine as the most delicate purfling of violins. The zodiacal figures are sketched about the edge. All inscriptions are in French. A French work, and judging by location of the equinox, of date about 1840. As a piece of furniture, also, it would be placed at about this date, being of the style of the Bourbon Restoration (1814 ——).

Nocturnals. The nocturnal seems to have been described first in 1533 by Apianus[12] (Peter Bennewitz 1495–1552). It consists of a disk with a central perforation through which the observer looks at Polaris with the plane of the instrument perpendicular to

[11] Gunther, Astrolabes of the World, Oxford, 1932, p. 501.

[12] Instrument Buch durch Petrum Apianum, Ingolstadii An. MDXXXIII.

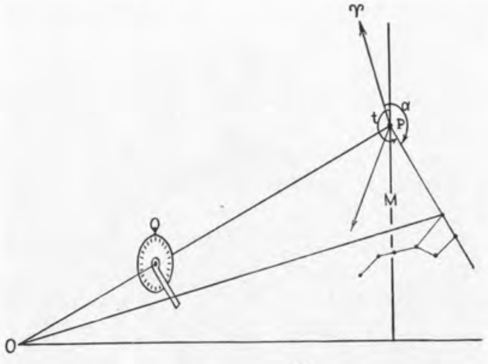


FIG. 35. THE PRINCIPLE OF THE NOCTURNAL.

the Earth's axis, the meridian of the instrument in the plane of the celestial meridian (Fig. 35). A protruding arm is rotated about the center until it is directed toward the star for which the instrument is constructed, generally α Ursae Majoris (Dubhe) or β Ursae Minoris (Kochab). If for α Ursae Majoris, the instrument is graduated to read 11 hours when that star is at upper culmination. When a setting is made, the sidereal time is then read directly. This can be transformed to solar time either by mental calculation or by instrumental means. The instrument does not permit of accuracy, so never attained great vogue.

Suppose the hour angle of Dubhe to be 15 hours. Since the right ascension is 11 hours, the sidereal time (right ascension plus the hour angle) is 2 hours. If at the time of the above observation the Sun's right ascension is 18 hours then the hour angle of the Sun (the apparent solar time) is 8 hours.

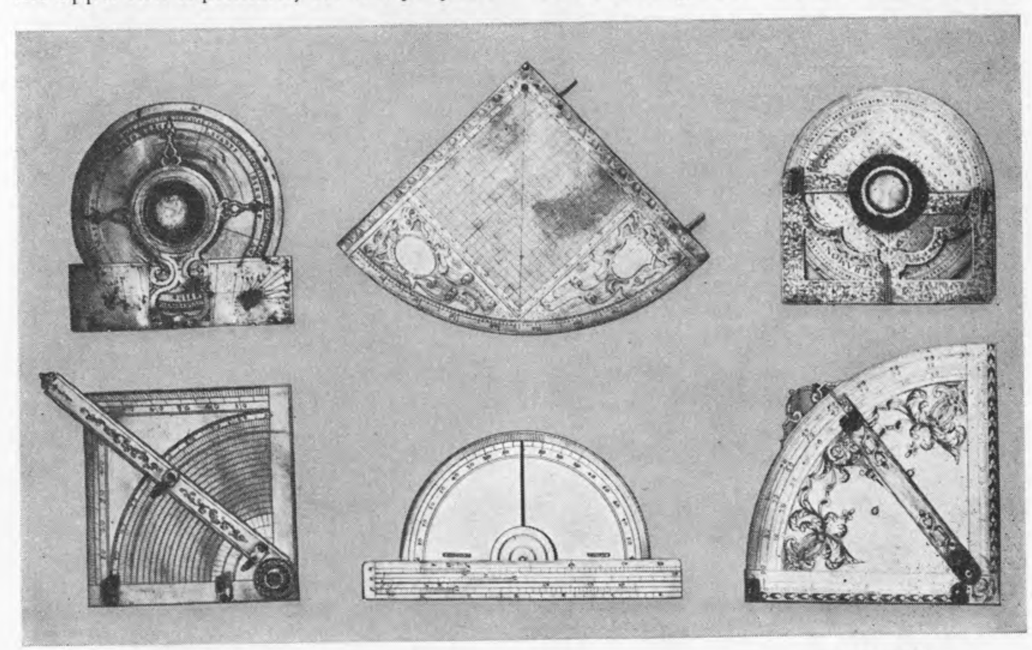
A.M. 333. A.M. 329. A.M. 334.
A.M. 330. A.M. 336. A.M. 335. A.M. 332.

FIG. 36. A GROUP OF SEVEN NOCTURNALS OF THE LATTER PART OF THE SIXTEENTH CENTURY.

The Collection contains eight instruments primarily nocturnals but the nocturnal also appears as an auxiliary in several other pieces, for example the Cole calendar, A.M. 363, to be mentioned later. Seven nocturnals are illustrated in Fig. 36. The only signed nocturnal of the collection, A.M. 331, "Antonius Giamin fecit Romae Anno Dm 1592" is not shown in the figure. Three others are dated—A.M. 330 "Romae 1578," A.M. 333 "1589," and A.M. 334 "1572." The largest one shown, A.M. 329, diameter 125 mm, bears also a Moon calendar and diagrams for astrological purposes. Four of them, A.M. 332, 334, 335, 336, have so many features in common that they are probably from the same master. They resemble that illustrated in Fig. 136 of Rohde's "Wissenschaftliche Instrumente." A.M. 330, lower left in Fig. 36, is the most beautiful nocturnal of the collection.

Quadrants, Octants, Sextants, Backstaff. The Collection contains several quadrants, octants, and sextants. All of the instruments of Fig. 37 may be used for measurement of altitude; A.M. 179 in the center of the upper row is primarily for this purpose. This instrument, radius 149 mm, is of fine gilt or ormolu finish, unsigned but resembles the work of Habermel. Instruments of this character in enlarged form with fixed quadrant and pivoted alidade (or, later, telescope) mounted in the meridian as a mural quadrant or in a vertical circle with motion also in azimuth, were the principal observational equipment for position astronomy of the most prominent observatories until near the end of the eighteenth century, and this in spite of the fact that Roemer had invented the meridian transit instrument and pointed out the advantage of a full circle at the end of the seventeenth century. Some of the mural quadrants were very large; that of Tycho 9-foot radius, of Bradley 8-foot radius.

A.M. 180 (Fig. 38) is a beautifully engraved octant inscribed "C T D E M 1618," Christoph Trechsler der (Dresden?) Edler Mechanikus. (. . . .–1624). The diagonal scale provides direct reading to 10′. It is prior to the invention of the vernier. There are four other pieces by this master in the collection. In the engraved ornamentation of the octant is a coat-of-arms "Johan Wilhelm Herzog zu Sachsen Gulich Cleve und



A.M. 159. A.M. 179. A.M. 158.
A.M. 182. A.M. 143. A.M. 183.

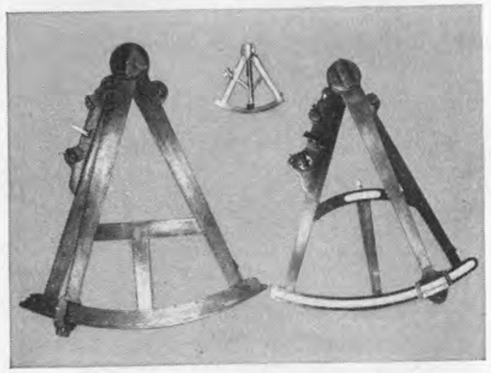
FIG. 37. SIX QUADRANTS OF VARIOUS FORMS.

FIG. 38. A.M. 180. AN OCTANT BY CHRISTOPH TRECHSLER OF DRESDEN, 1618.

Bergk" but of greater interest for science are the types of mathematical instruments to the right of the arms. The juxtaposition of instruments of war and peace brings to mention that Trechsler made a machine gun (mitrailleuse) in 1595–8. It was not put into use for it was said that 5000 musketeers were cheaper than 500 of the weapons. This decision does not seem so antiquated when compared with the preparedness programs of modern legislators.

There are three large reflecting octants in wood; two appear in Fig. 39. A.M. 478 has the circle engraved on wood with a diagonal scale for readings to 2′. In A.M. 479 the circle is of ivory and is read by a vernier to 1′. The fact that one of these has a diagonal scale and the other a vernier does not fix the relative date, for both of these devices far antedated the octants. The inventor of the diagonal scale, or transversal, is not known, though the names of Homelius of Leipzig, teacher of Tycho Brahe, and Kantzler of London are mentioned in this connection. It is probably contemporary with the nonius, for Tycho Brahe (1546–1601) adopted it after trying the nonius. The nonius was the invention, 1542, of the Portuguese writer on mathematics and navigation, Pedro Nunez (1492-1577), who also is credited with the invention of the loxodromic line. The vernier is later, 1631, by the Frenchman Pierre Vernier of Ornans (1580–1637). The small sextant, A.M. 184, which stands above the octants is signed "Brander und Hörschel in Augsburg" (c. 1760). To whom belongs priority in the invention of the reflecting octant, or sextant into which it developed, is somewhat debatable. Newton's description of the invention was communicated to Halley in 1699 but was not published until 1742, after Newton's death. Thomas Godfrey (b. 1704 Bristol Township, Philadelphia; d. 1749 Philadelphia) seems to have anticipated John Hadley (1682–1743) by a year or more. His instrument was in use in 1730[13] while that of Hadley was described to the Royal Society in its meeting of 13 May 1731. The Royal Society awarded the two equally.[14] This invention is probably the first of an important scientific instrument to come out of America. The third octant was acquired from Mrs. H. H. Turner.

The Museum has also a sextant by Cary, No. 3379, and one by W. Campbell & Co., Hamburg, gifts of Mr. Harry Oppenheimer of Chicago; one by Brandis and Sons,



A.M. 184.
A.M. 478. A.M. 479.
FIG. 39. EARLY OCTANTS AND REFLECTING SEXTANT.

[13] H. E. Gillingham, Some Early Philadelphia Instrument Makers, Penn. Mag. of History and Biography, Oct. 1927.

[14] Grant, Hist. Phys. Astron., London, 1852, p. 482.

Brooklyn, N. Y., gift from the U. S. Navy, marked "No. 1736"; and one by Chrichton, London, on loan from Mr. Elmer B. Tolsted of Chicago.

The firm of Cooke, Troughton & Simms, Ltd. of London has recently presented to the Museum an interesting backstaff. The backstaff or "quartier anglais" was invented and described in 1594 by the great English navigator, John Davis, (1550?–1605) for whom Davis Strait is named. Robert Hooke seems to have made an improved form in 1666. The example now presented bears the inscriptions

❖COLE ✿ MAKER ✿
LOMBARD ✿ STREET ✿ LONDON ❖
and
✿ IOSEPH IACKSON ✿ 1746, presumably the owner's name. This instrument is probably by B. Cole, successor to Thomas Wright c. 1750. Cole was in turn succeeded by John Troughton, Edward Troughton, Troughton and Simms, and now by the generous donors.

Time-keepers. All appreciation of time is related to motion. The pulse marking the rhythmic surge of blood through the arteries, the shortening of the burning taper, the creeping shadow of a gnomon, the discharge of water or sand through an orifice, the oscillation of a pendulum or balance wheel,—may be used to measure the rotation of the Earth and give the time of day. The history of the development of devices for indicating time is told in many museums. Comments on the various instruments here will be made in the order Dials, Hour-Glasses, Clocks.

Sun-Dials. The invention of the Sun-dial at least in its spherical form is attributed to both Eudoxus (404–356 B.C.) and Apollonius (250–180 B.C.). The flat dial came into use with Aristarchus of Samos (310–230 B.C.). In later developments the Dial has taken many forms: multiple-faced or polyhedral, pillar or chilindre, sometimes called Shepherd's dial, ring, cruciform,

FIG. 40. CABINET WITH AN ASSORTMENT OF SUN-DIALS OF VARIOUS FORMS.

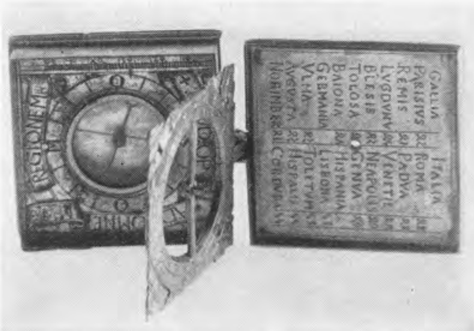


FIG. 41. A.M. 288. A SUN-DIAL DATED 1479.

compass dial, equatorial, horological ring, universal ring dial, but all depend on the position of the Sun in its daily course; its hour angle, or its altitude. All of these forms and numerous special forms are represented among the hundred or more dials of this Museum. Some are large, intended for fixed mounting; others are small portable dials, pocket dials such as that mentioned in "As You Like It":

"And then he drew a dial from his poke
And looking on it with lack-lustre eye
Says very wisely, 'It is ten o'clock:
Thus we may see,' quoth he, 'how the world wags.' "

A general view of one of the dial cabinets (Fig. 40) will indicate the variety. Fully half of the dials are signed and among the names are found those of the most celebrated instrument makers of the years

FIG. 42. A.M. 280. HORIZONTAL DIAL WITH ARMORIAL DEVICES.

when dialling was at its best. No attempt will be made here to trace the development,—the transition from the scaphe to the horizontal dial; the displacement of the unequal or temporary hours by equal hours; the introduction of the inclined style, parallel to the Earth's axis, the Polus, by Puerbach, von Gmunden, Regiomontanus; the introduction of the compass by Puerbach; the equatorial dial; ring dial, and universal ring dial developed especially in England—but rather we shall be content here to discuss briefly a few of the specimens, reserv-

FIG. 43. A.M. 277. HORIZONTAL DIAL FROM INDIA.

ing for another occasion a more complete treatment.

The ring dial, A.M. 307, on which all inscriptions are in Gothic, is one of the oldest of the Collection, but the dial which bears the earliest date is A.M. 288 (Fig. 41). On the folds of a banderole it bears the inscription: M-ARIA-H-I-LFVN-S-NA-14-79. "Mary help us, Anno 1479," also a statement of the adaptability of the dial to all latitudes, "ISTVD OPVS AD OMNEM REGIONEM." The figures are Gothic, as may be seen in the table of colatitudes for PARISIVS (Paris) 42, REMIS (Reims) 41, LVGDVNV (Lyon) 45 BLESIS (Blois) 42, etc. This is one of the earliest examples of the equatorial, compass dial.

A.M. 280 (Fig. 42) carved on stone and colored (360 x 340 mm) is of especial interest because of the armorial devices. I. Above

to the left is the coat-of-arms of the Casa Savoia with the motto "FERT-FERT-FERT" (Ready) derived from Fortitudo Eius Rhodum Tenuit. II. On its left is found the same combined with the fleur-de-lis of France, the union of the House of Savoy and the House of Orleans. Louise of Savoy married Charles d'Anjouleme of the House of Orleans. Their son (1494–1547) became king of France, Francis I. III. The coat-of-arms above the style bears dexter the three crescents of the Strozzi, sinister is unknown. The dial bears the inscriptions "SOLO MVTATVR ASPECTV" and "GEMINO PRAESIDIO

FIG. 44. A.M. 249. A CARVED IVORY DIAL OF THE SIXTEENTH CENTURY.

TVTVS." This dial is undated and unsigned but was probably engraved for the Strozzi family who so long fostered this collection of instruments.

A.M. 277 (Fig. 43) is faultily described in the Mensing Catalogue. The inclination of the style and the bearings of the hour-lines place the latitude at about 28°. This together with the engraved monkey places this dial in India, possibly Jaipur or Delhi. It is the most southern dial of this collection. The style is wrongly placed; its foot is not in the prime vertical. The morning hours VI, VII, VIII are incorrectly inscribed. A well-nigh illegible device seems to give the year as MDXI. (325 x 330 mm).

A.M. 249 (Fig. 44) is a beautifully en-

FIG. 45. A.M. 300. A DIAL TO INDICATE THE MINUTE BY "I. STÖCKL."

graved ivory dial of South Germany of the sixteenth century. The cover, probably of earlier date, is carved in high relief showing the scourging and bearing of fagots for the immolation pyre. The height is 84 mm.

Increase of accuracy over that attained by Martin, Rugendas, Vogler, etc. (see in Museum dials by these makers or that by Delure loaned by Mrs. James G. S. Orchard

FIG. 46. A.M. 297. A DIAL BY WERNLE OF PRESBURG.

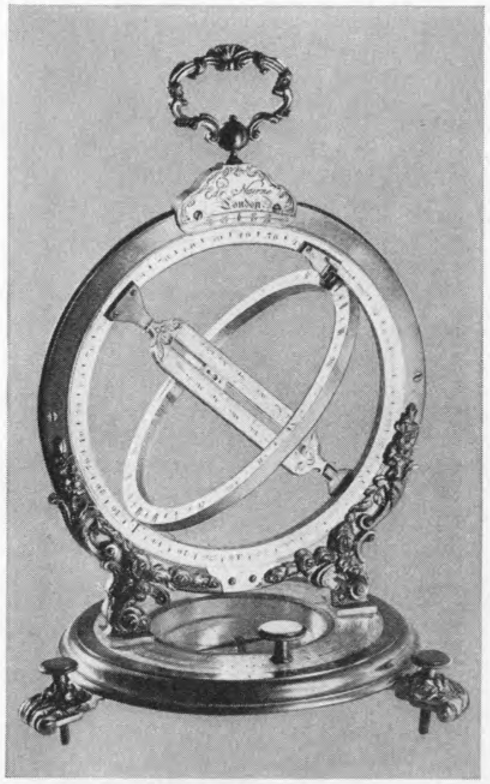


FIG. 47. A.M. 314. AN ELABORATELY DEVELOPED UNIVERSAL RING DIAL BY EDWARD NAIRNE, LONDON.

of Evanston) was accomplished in the dials by Claude Dunod of Dusseldorf (French origin) in 1710–15. He added an auxiliary indicator with a minute hand. This was geared with the main dial (which stood in the equatorial plane) but was attached to an alidade to be directed toward the Sun, the minute-hand rotating through the sixty minutes with each 15° change of hour angle. Dunod is not represented in the collection but there are two dials of other makers which illustrate the type. A.M. 300 (Fig. 45) signed "I. Stöckl" resembles the work of Dunod very closely.[15] A.M. 297 (Fig. 46) signed "Joh. Georg Wernle Presburg" (c. 1750) does not have the auxiliary dial but the hands are geared to a rotating disk carrying the alidade. The dial face is enameled. A more elaborately developed dial of this type is seen in Fig. 48.

A.M. 314 (Fig. 47) presents an example of universal ring dial in its perfected form. The elevation of the pole and the motion in azimuth effected by rack and pinion are read with verniers to the nearest minute of arc. The pinnule is movable with an accurate scale for its adjustment for the date. There is an excellent compass, a pair of levels also in the compass box, height 432 mm. It is signed: "Edw. Nairne, London." Nairne was a versatile instrument maker; Repsold[16] cites an equatorial mounting by him of the year 1771.

A.M. 302 (Fig. 48) is one of the most beautifully constructed dials in the Collection. It is the work of "J. J. Sauter, Stockholm" whose tellurion clock is shown in Fig. 25. It is a ring dial with the adaptation of the geared clock face to yield the minute. The graduated plate which re-

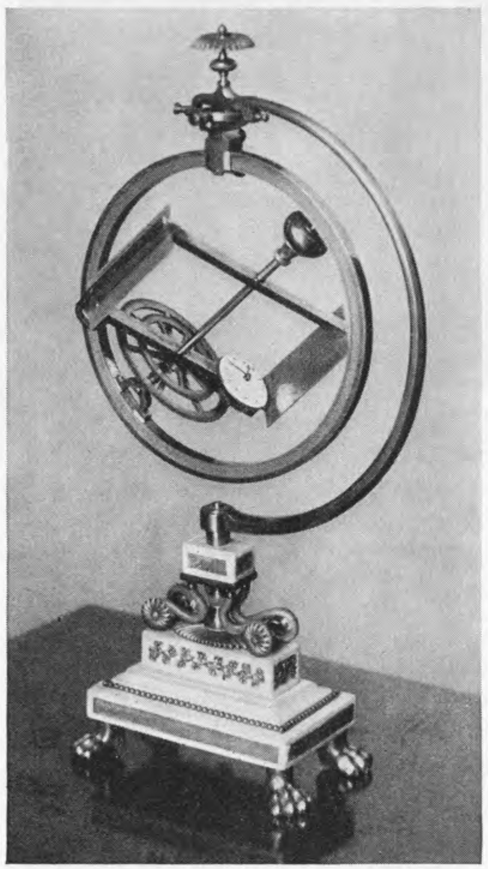


FIG. 48. A.M. 302. A MODIFIED RING DIAL BY SAUTER OF STOCKHOLM.

[15] Rohde, Die Geschichte der Wissenschaftlichen Instrumente, Leipzig, 1923, p. 30, Abb. 34, 35, 36.

[16] Repsold, Astronomische Messwerkzeuge, Leipzig, 1908, Fig. 98.

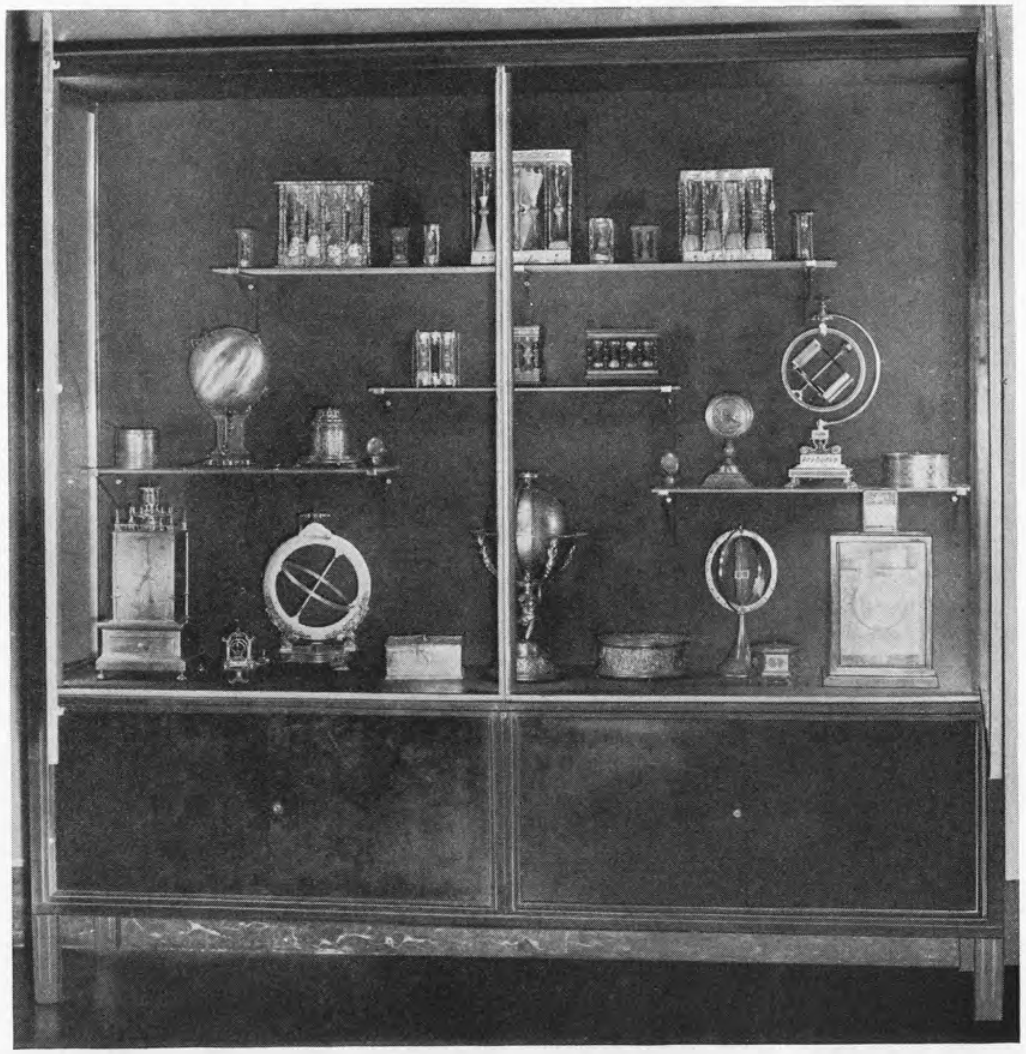


FIG. 49. A CABINET FOR HOUR-GLASSES, CLOCKS, AND DIALS.

ceives the solar image bears also curves to permit allowance for the equation of time. It is a close replica of the instrument shown in Fig. 125 of "Die Geschichte der Zeitmessung und der Uhren"—Ernest von Bassermann-Jordan Vol. I E "Theorie der Sonnenuhren" Joseph Drecker, Berlin-Leipzig 1925. Such dials as these of Nairne and Sauter were perhaps the last effort in the unequal contest between dials and the rapidly improving clocks and watches.

Hour-Glasses and Clocks. Instruments which determine or mark the time by the position of the heavenly bodies are dependent on clear skies. Clouds may have been the spur to the invention of the clepsydra, sand-glass, and clocks. The hour-glass or sand-glass and the clepsydra or water-clock are probably coeval. If so, the hour-glass has a life history of well over 2000 years. Its invention is, however, often attributed to Luitprand of Chartres, a monk who lived in the eighth century. The hour-glass has certain advantages over the water-clock; sand does not freeze nor evaporate, enclosed it may be kept dry and runs at a regular rate, a new supply is never needed.

The Museum possesses twenty-four hour-glasses, a few of which may be seen in

Fig. 49. Some of them bear master-marks: Stag, Posthorn, Lion, Comet, Imperial Orb. The mark of the Orb was used by Hans Ducher (Tucher) (1572?–1632?), see A.M. 173 (Fig. 54) but the hour-glass which bears this mark has the initials "H. M." and the date "1744." The quadruple glass to the left on the upper shelf has very white sand or perhaps finely ground eggshell.

The first mechanical clocks appeared in the thirteenth century, in Westminster 1288, Canterbury 1292, Caen 1314. The Tour de l'Horloge in the Palais de Justice in Paris was built in 1298 and shortly thereafter a clock was installed. De Vick's clock was erected there in 1364 or thereabouts. None of these early clocks made great pretense of keeping accurate time. They were frequently checked by sun-dials. The essentials of a clock are: 1, a device to give equal intervals of time (pendulum or balance wheel); 2, a device to keep the first in operation and release periodically the clock train (the escapement); 3, a recording dial. The first requisite was available after Galileo in 1583 discovered the isochronism of the pendulum but was not successfully adapted until 1657 when Huyghens presented his clock to the States General of Holland. Modern clock-making may date from that event. Collections of clocks and watches are frequently seen and furnish characteristic and valuable exhibits of the instrument makers' technique as well as the development of the timepiece itself. The French attained an early ascendency in clock-making probably due to Huyghens' residence in Paris (1666–1681). In the observatory of Leiden there is a clock signed "Thuret à Paris" constructed "suivant les indications de Huygens et lui appartenait" . . . "Thuret . . . a beaucoup travaillé pour Huygens et on rencontre son nom un grand nombre de fois dans la correspondance."[17] The revocation of the Edict of Nantes (1685) drove the clock makers, who were mostly Protestants, from France to London, Geneva, etc. France never regained her dominant position in this art.[18]

[17] Christian Huygens, H. J. Paris, Amsterdam 1929, p. 53.

[18] See Edmond Haraucourt, Mediaeval Manners Illustrated at the Cluny Museum, Librairie Larousse, Paris, p. 174.

FIG. 50. A.M. 377. A ROUND TABLE CLOCK OF ABOUT 1550.

Of the twenty clocks of the collection six are signed:

A.M. 378 "Cas. Bv." — Caspar Bushmann of Augsburg, (c. 1580).

A.M. 379 "V S"/W —The initials V.S. W were used by Ulricus Schniep (-d. 1588) by Victor Stark (c. 1600) and by Virgil Solis (c. 1550).

A.M. 383 "Johann Christoff Lang Inn Augspurg" (c. 1600).

A.M. 388 "J. B. Letter A Zug" (Switzerland 18th century).

A.M. 390 "Jean van Ceulen le Jeune Hague" probably the son of Van Ceulen the horologist who made Huyghens' planetarium in 1682.

A.M. 393 A so-called "Nürnberg Egg" by "Jacob Pouillet Clermont." Bears the arms "de la Tour d'Auvergne" and the device "Plutost Mort, Que Vaincu."

Another similar "Egg," A.M. 394, in the style of Salomon Chesnon of Blois, for insurance is provided with a small sun-dial. The works are missing, whether by accident or disgust of the owner over the inferior performance when compared with the dial is conjectural.

A.M. 377 (Fig. 50) is a very handsome piece, diameter 235 mm. The top bears an astrolabe design for the solar calendar, with engraved indices for the Sun and Moon. The case of gilt or ormolu, "feuervergoldet," is engraved in high relief with Orpheus and the charmed animals, stag,

FIG. 51. GLOBE CLOCK BY ISAAC HABRECHT, STRASBOURG, 1646. LOANED BY A. S. DREY OF NEW YORK AND MUNICH.

boar, cock, rabbit, wolf, bear, lion, birds. On the bottom is figured a perpetual calendar and centrally, Adam and Eve and the Serpent under the tree of the forbidden fruit. Engelmann notes that the clock is in the style of Virgil Solis (c. 1550) and Jost Amman (c. 1568). But Milham in "Time and Timekeepers" shows a quite similar piece from the British Museum "probably by Jeremias Metzger of Augsburg, and dates from about 1530."[19] This piece Mensing obtained from A. S. Drey who in turn had purchased it from a Russian collection.[20]

The clock in Fig. 51 is in the Museum on loan from Mr. A. S. Drey of New York and Munich. It should perhaps have been noted also under Celestial Globes. This rare globe-clock stands 470 mm high, the globe has a diameter of 290 mm. Its great interest aside from its artistic merit lies in the name of the maker *"Isaac Habrecht."* He is of that family of Strasbourg horologists of whom Ungerer writes in "Les Habrecht, une dynastie d'horlogers Strasbourgeois au XVI^{e} et XVII^{e} siecle."[21] Isaac Habrecht (1544–1620) is known as the constructor of the most famous clock in the world, the great astronomical clock of the Cathedral at Strasbourg, a task finished in 1574. (It should be noted that the present Strasbourg clock is a reconstruction by Jean Baptiste Schwilgue done in 1838–42.) This Isaac Habrecht could not have made the clock exhibited here for it bears the date 1646. Neither could his son Isaac II, a physician, mathematician, astronomer, have made it for his death occurred in 1633, but its author was his grandson Isaac III (1611–1686) "Horloger a Strasbourg."

[19] Willis I. Milham, Time and Timekeepers, New York, 1929, Fig. 77, opposite p. 125.

[20] See Gunther, Astrolabes of the World, p. 536.

The Museum has a small Japanese clock, a gift of Mr. William B. Parmelee of Chicago; from Mr. Adler a tall clock of Chinese construction with a regulator of Foliot type; of modern time-pieces, a chronometer, T. C. Negus and Co. No. 562, from the U. S. Navy, and a small electrical clock from the Hammond Clock Co. Also, there is a small table clock signed Rene Pierre Bouchet of Luxembourg, engraved with the royal Luxembourg coat-of-arms, on loan from Mr. David B. Nachemsohn of Chicago.

Just as ancient Time-keepers sufficed to show the inequality of apparent solar days and led eventually to the adoption of Mean Solar Time, so modern astronomical clocks in their present refinements (in the Shortt Free Pendulum Clock of the Synchronome Company of London, for example) may indicate inequality of period in the rotation of the Earth itself.

Calendars. In the century before the promulgation of the Gregorian Calendar, 1582, there was so much agitation for calendar reform that many clever, able mathematicians gave their attention to the problem. The results of their labors were wrought into the form of various ephemerides and perpetual calendars. The confusion which followed the announcement of the New Calendar served as added impulse for their design.

There are fourteen instruments in the collection classified primarily as Calendars.

[21] Theodore Ungerer, Edition des Archives Alsaciennes d'Histoire de l'Art, Strasbourg, 1925.

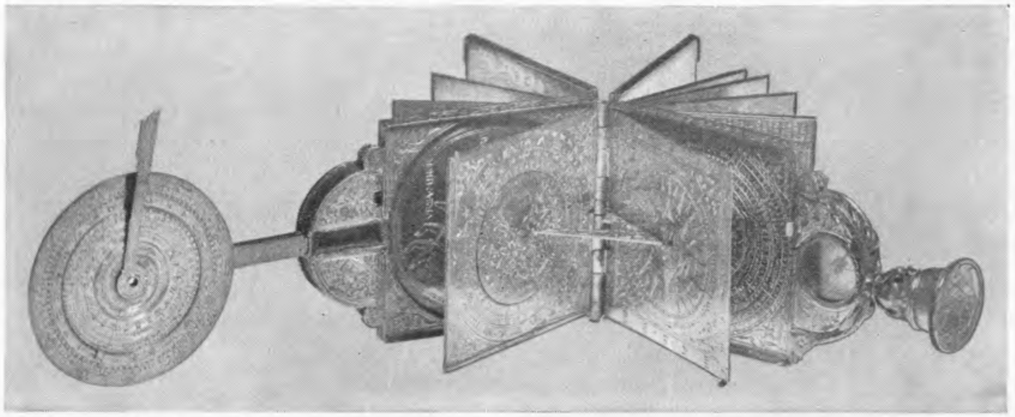


FIG. 52. A.M. 363. A CALENDAR, EPHEMERIS, SUN-DIAL, NOCTURNAL, QUADRANT. OF ENGLISH MAKE BY "V. C. 1557."

On many additional instruments analogous devices are noted and on the other hand, several of the fourteen have added features. They bear distinguished names for authorship:

A.M. 363 "V. C."
A.M. 364 "Christofforus Schisler"
A.M. 365 "Christophorus Schissler"
A.M. 366 "Io. Bonius"
A.M. 367 "Barent Hendricke"
A.M. 368 "Erasmus Habermehl"
A.M. 369 "Schindler"
A.M. 375 "Sevin"
A.M. 477 "Johannes Melchior Volkmair"

All are of deep interest but two are selected as representative of the finest design and craftsmanship.

A.M. 363 (Fig. 52) is one of the finest pieces of the entire Collection. It has an elaborate calendar, extensive ephemeris for 1556–1585, a sun-dial, nocturnal, quadrant, compass, a map of the world, called "VNIVERSAL COSMOGRAPHIE,"—a veritable compendium of knowledge. All parts fold like a book into a compact pack, 69x69 mm, held by small clasps with angel heads engraved on them. The inscriptions are in Latin and English: "Tabula + medii + motus + solis." "A TABLE FOR THE HOVRES OF PLANETS . . ," "A TABIL OF QVANTATIE OF DAIS," "for the mone bi niet," "AEQVINOCIALI ELEVATIO"

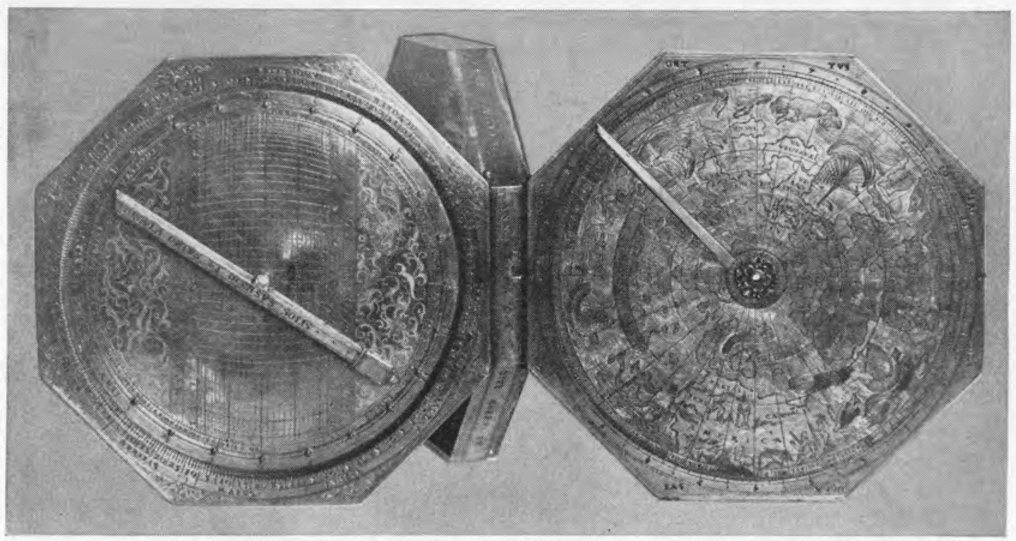


FIG. 53. A.M. 365. A CALENDAR, SUN-DIAL, WORLD MAP BY CHRISTOPHORUS SCHISSLER, 1559.

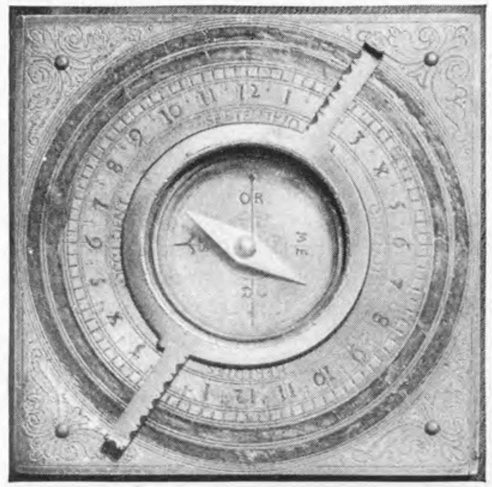


FIG. 54. A.M. 173. A COMPASS BY HANNS DUCHER, 1609.

are given only for English cities, DOVIR, LONDON, LYNKON, YORKE, NEWCASTEL, BERWYKE, EDYNBORRO, EXONIA, CANTOR, COLCEST, HERTFORD, LEICESTER, NOTISHAM, CESTRIA (Chester). It is signed "V. C. 1557."

The whole is of fine gilt, handsomely engraved; a coat-of-arms in the handle, to be used as a seal; an armed figure facing a giant, perhaps David and Goliath; an armillary sphere on the pediment. This is an exceedingly interesting piece: of it Engelmann writes "Sehr beachtliches Erzeugnis eines bedeutenden Instrumentenmachers oder Goldschmiedes, der wohl unter Aufsicht eines hervorragenden Gelehrten seiner Zeit arbeitete." In many respects similar to the "V. C." pocket dial and calendar at the Ashmolean Museum.[22] Gunther suggests that "V. C." stands for VMFREDVS COLE perhaps the father of Humfray Coole. (Humphrey Cole.) The coat-of-arms is parted with lozenges dexter and a lion sinister. The lozenges may be for Sir William Fitzwilliam (1526–1599) Lord Deputy of Ireland. The lion is too common to be easily assignable. The wife of Sir William was Agnes, daughter of Sir William Sidney.

A.M. 365 (Fig. 53) is another important piece as unmistakably German as A.M. 363 is English. But this piece is signed, and by the foremost German instrument maker of his day "CHRISTOPHORVS SCHISSLER ME FECIT AVGVSTE VINDELICORVM" (Augsburg). There are four signed pieces in the collection by this master and five others that are probably of his authorship. The piece bears an interesting polar projection map of the Earth to the Tropic of Capricorn, the seas in silver, the land in brass-gilt. The land forms are crude, North America, called "BACCALEARVM" no larger than "CVBA." Drake had not yet made his great voyage. The sea however floats great ships, also fearsome monsters, and two-tailed mermaids, melusines. On the inner surface there is an engraved map of Germany but taking in Leiden, Ghendt, Remis, Lecern, Innsbruck, Cracow. It bears a horizontal sun-dial with scales for seven latitudes 39° to 57°. Latitudes of many European cities are given. It has a central compass, a calendar with device for lunar phases and configurations, a nocturnal. About the periphery the date "ANNO 1559" and the inscription "SIVE MARE ET TERRAS SEV COELVM ET TEM-

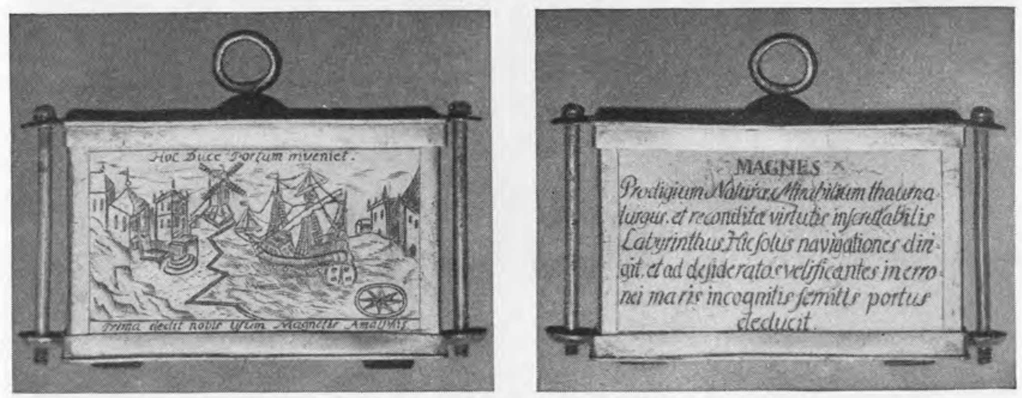


FIG. 55. A.M. 414. A NATURAL MAGNET ENCASED IN SILVER.

[22]Gunther, Early Science at Oxford, II, Oxford, 1922, p. 279.

PORA QVAERVIS ME DVCE PERPETVO CERTIOR ESSE POTES" which may be rendered "Whether you are searching out the sea and the lands or the sky and the seasons with me as your constant guide you can go more safely" or "Whether you seek sea and land or sky and the seasons you will ever be able to be well assured with me as your guide."

From the Hamilton-Sangamo Corporation the Museum has received a small moulded paper replica of the great Aztec Calendar Stone of the National Museum of Mexico, an instrument of extraordinary interest.

Compasses and Natural Magnets. One turns naturally from the legend on the Schissler calendar to a consideration of compasses. So many instruments of the Collection—sun-dials, circumferenters, etc., bear compasses that it is quite impossible to make a clear-cut classification. A.M. 173 (Fig. 54) is a compass signed "hanns ducher (sometimes written Tucher) faci ch badt 1609" (1572?–1632?). It bears also his "meistermarke" the imperial orb (reichsapfel). (Another mastermark used by a Hans Tucher of this family is a crowned serpent.) It is a fair example of the work of this master who was a distinguished member of a family of instrument makers. Note that the numeral four retains its Gothic form. The spandrels have characteristic engravings.

The origin of the compass certainly rests

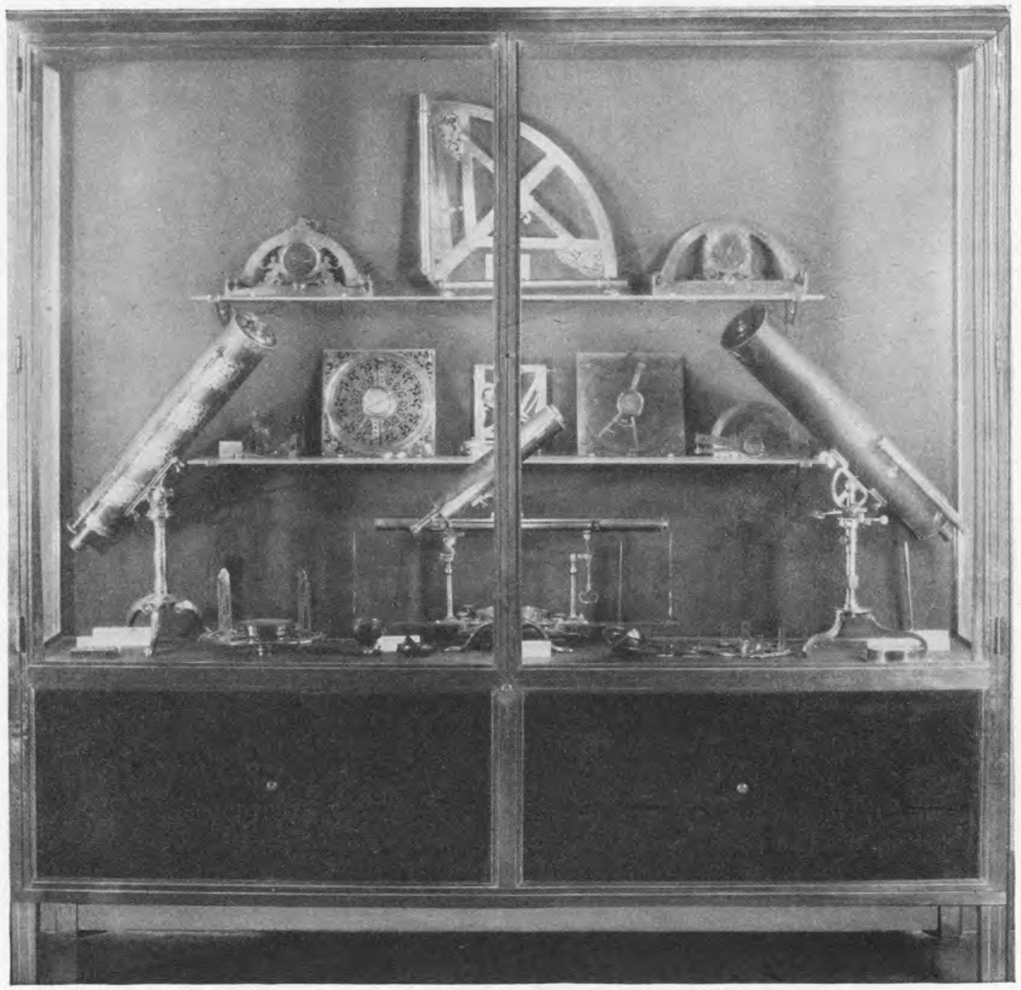


FIG. 56. A CABINET OF GEODETIC INSTRUMENTS AND TELESCOPES.

on the discovery of the curious properties of the lodestone. There are two of these natural magnets in the cabinets, A.M. 414 and 415, both of which preserve their potency. The first is shown in Fig. 55 in front and back views, picturing a ship home from its farings, sails furled, safe in the harbor. English equivalents of the inscriptions on the face are "With this guide he will find the harbor," "Amalfi first gave to us the use of the magnet," words perhaps quoted from the Italian poet Antonio Beccadelli (1394–1471) sometimes called "Panormita" from his birthplace Panormus (Palermo), who has the commemorative line "Prima dedit *nautis* usum Magnetis Amalphis." The longer legend on the back may be rendered: "The magnet a prodigy of nature, a wonder worker of marvels, an inscrutable labyrinth of hidden virtue. This alone guides navigations and to their desired harbors leads sailors on the unknown paths of the uncharted sea."

Makers of ancient instruments wrought with deep sincerity and often with pious devotion. Perhaps in our great factories we have lost something of this pride and devotion. In our day it seems a little naïve that a great pair of rough, wrought-iron calipers or dividers for use about a forge

A.M. 94
A.M. 147

FIG. 57. A GRAPHOMETER BY PIERRE SEVIN OF PARIS AND A PROTRACTOR PROBABLY OF THE SAME AUTHORSHIP.

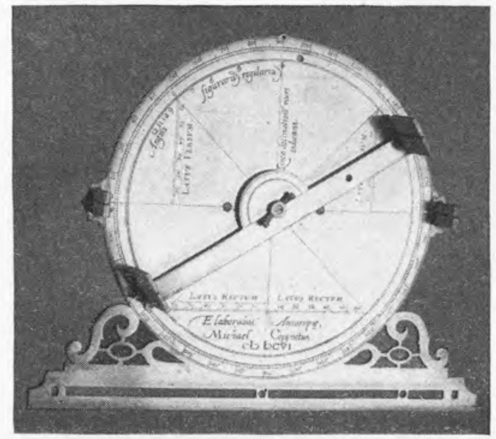


FIG. 58. A.M. 149. A CIRCUMFERENTER BY COIGNET, 1606.

should be engraved "Joseph Maria Jesus," as are A.M. 80 and 85. Religious legends are found on many of the early sun-dials. This practice is nowhere better illustrated than by the inscription on the natural magnet A.M. 415: "Gleich wie der Magnetstein Das Eisen an sich Ziehet, Also Ziehet Christus Jesus die Seelen der Gläubigen auch an sich."

In contrast to the ancient instruments the Museum has a binnacle and compass which crossed the Atlantic on the replica of the Santa Maria when Spain dispatched the duplicated caravels of Columbus to the Columbian Exposition in Chicago in 1893. Gift of the South Park Commissioners. Also it has a modern gyrocompass and repeater from the U. S. Navy.

Geodetic Instruments. Many of the instruments of geodesy are utilized also in astronomy: the quadrant, graphometer, circumferenter, torquetum, theodolite, levels, etc. A cabinet containing a few of these instruments and some telescopes as well is given in Fig. 56.

The Graphometer, a graduated half-circle with diopters, a glorified protractor with alidades for sighting, was invented in the second half of the sixteenth century. It was first described by Philippe Danfrie in 1597. Its functions are amply set out in his title page, "Declaration de l'usage du graphomètre par la pratique duquel on peut mesurer toutes les distances des choses de remarque qui pourront voir et discerner du lieu où il sera pose: et pour arpenter terres, bois, prés et faire plans de villes et forteresses, cartes géographique et généralement toutes mesures visibles; et ce, sans reigle d'arithmétique."[23] To avoid arithmetic its readings are transferred to a plane table (planchette) with the aid of a protractor (rapporteur).

The collection contains graphometers signed by "Capitan Petru Spera Deo," A.M. 145; "Pierre Sevin a Paris" (instrument maker for Cassini), A.M. 147; "Lasnier a Paris aux Deux Globes," A.M. 148; "J. Maretz f. Aix," A.M. 157. The Sevin instrument, A.M. 147, of about 1670 and a protractor, A.M. 94, are reproduced in Fig. 57. The graphometer is provided with a diagonal scale reading to 0°.1. A similar figure is found in the volume by Laussedat (his Fig. 22, p. 75). The protractor, practically identical with that in Laussedat, is unsigned unless the "S R" are initials. They may stand for Sevin A Paris, the letter which appears as an R may be a monogram AP.

The Circumferenter or full-circle diopeter instrument, in France called the "Cercle Hollandais" is sometimes attributed to Jan Pieterszoon Dou of Leiden about 1610. It is described by him in a volume first published in 1612; but the Conservatoire National des Arts et Métiers has a circumferenter by Coignet dated 1606. Also, in the Chicago Museum there is one, A.M. 149 (Fig. 58) inscribed: "Elaborat Antuerpie Michael Coignetus CIↃ IↃ CVI" (1606). These two instruments by Coignet are certainly among the oldest circumferenters extant. In the Museum there are also signed ones by "D'Amery Matemat. A Bruxelles" (A.M. 150, c. 1630), "Oller Fecit Amstel" (A.M. 154, c. 1660), "J. Bennett London" (A.M. 156, c. 1750).

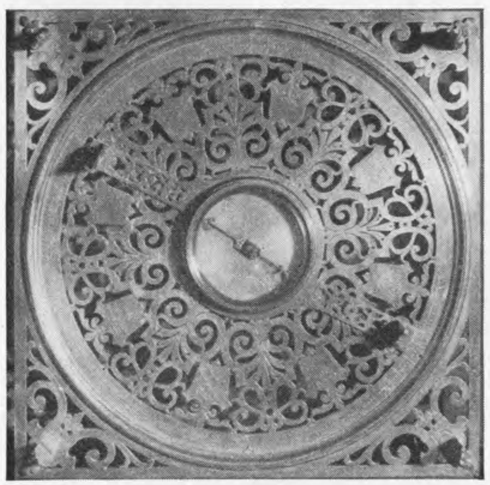


FIG. 59. A.M. 153. A CIRCUMFERENTER BY VAGNARELLI OF URBINO, ABOUT 1640.

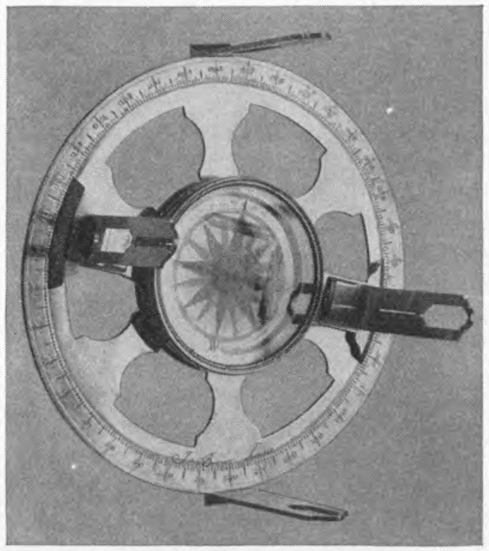


FIG. 60. A.M. 156. A CIRCUMFERENTER AND COMPASS BY J. BENNETT, LONDON, ABOUT 1750.

A.M. 153 (Fig. 59) is unsigned but is like in style in all particulars—compass, alidades, wind directions on the eight shields (rosa dei venti), general filigree ornament within the circle and in the spandrels—to the work of Vagnarelli, a master of Urbino of the seventeenth century.[24] It has neither diagonal scale nor vernier though it is subsequent to these two inventions. A further development of this instrument is shown in A.M. 156 (Fig. 60) signed "J. Bennett London." It has a vernier to read to 5′. (This may be the Bennett of Cork of the end of the eighteenth century.)

With the obvious advantages of the circumferenter, it is curious that it did not immediately displace the graphometer. It seems rather that both of them were finally displaced by the Torquetum and Theodolite. These instruments by virtue of the two circles perpendicular to each other, whether placed as an alt-azimuth or equatorially, enable the two coördinates to be read with one pointing. The statement is found that the torquetum was invented by Naer ed din about 1260. Regiomontanus (1436-76) described the torquetum and assigned Geber as inventor about 1145. It was used as early as 1540 by Apianus in Ingolstadt. The theodolite was developed by Leonard Digges before 1571. There is no real distinction between these instruments. The use of a clinometer on a plane table by Praetorius (Richter) (1537-1616) at Wittenberg was of this same period.

There is only one torquetum in the Museum but it is an excellent piece, A.M. 187 (Fig. 61). It is signed "P. Danfrie." This may possibly be the Philippe Danfrie, the inventor of the graphometer, but may be of a later generation. The instrument may be used as an alt-azimuth or as an equatorial adaptable for any latitude, setting by the quadrant. On the small compass the four cardinal points are marked with letters of Italian wind directions except that east is indicated with the more unusual square cross.

[23] Laussedat. Recherches sur les Instruments les Méthodes et le Dessin Topographiques, T. I., Paris, 1898, p. 76-77.

[24] Rohde, loc. cit., Abb. 93, p. 69.

FIG. 61. A.M. 187. A TORQUETUM BY P. DANFRIE, OF EARLY YEARS OF THE SIXTEENTH CENTURY.

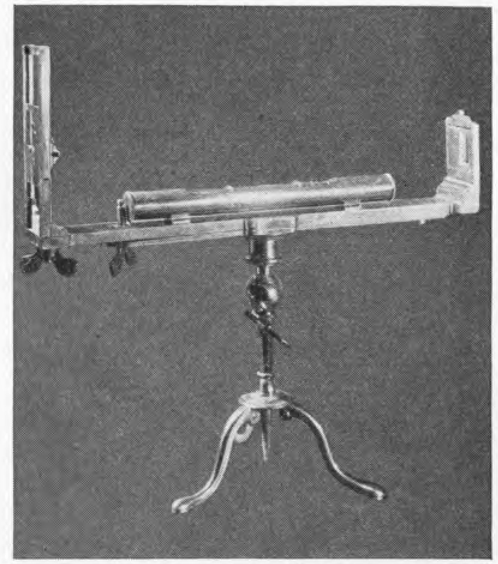


FIG. 62. A.M. 190. A LEVEL, "NIVEAU DE PENTE" BY MEURAND OF PARIS, 1788.

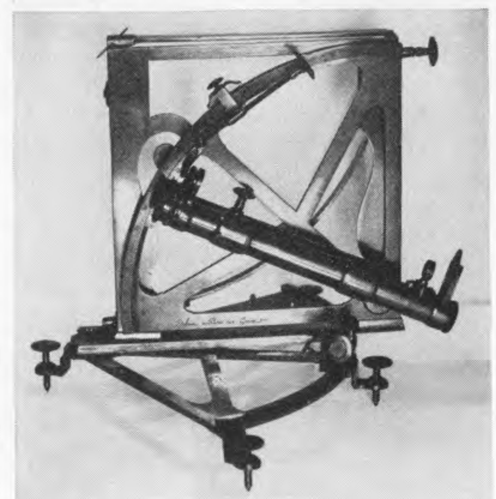


FIG. 63. A.M. 439. A TELESCOPIC QUADRANT BY DU BOIS OF PARIS, ABOUT 1780.

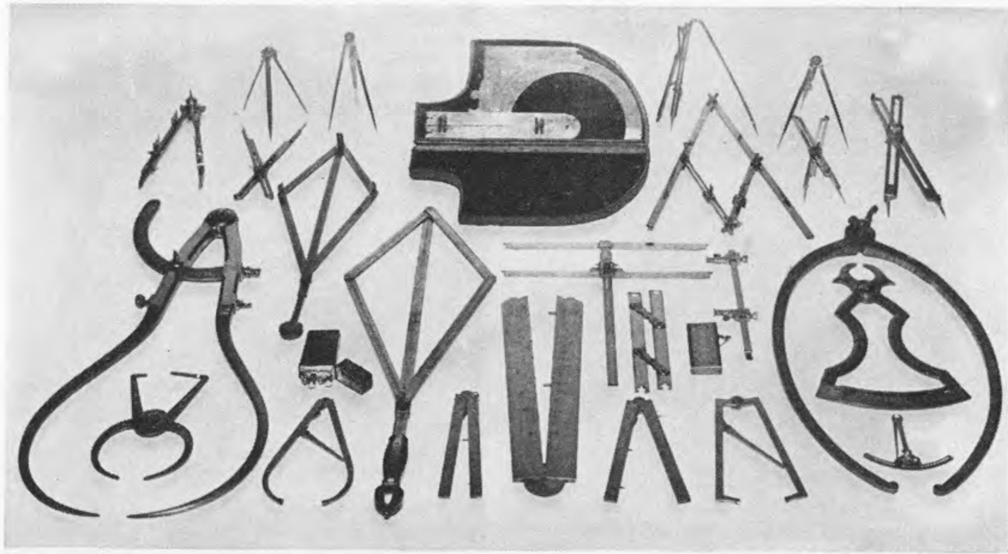


FIG. 64. A GROUP OF MATHEMATICAL INSTRUMENTS.

The Museum has two theodolites, gifts of the U. S. Navy, one by Ertel & Sohn, the second by Stackpole. The latter instrument was used in transit of Venus expeditions in 1874 and 1882.

The Level was invented in the year 1666 by the French scholar, traveller, orientalist, Melchisedech Thévenot (c. 1620-1692). It received scant attention in France, but was adopted in England and Italy and from those countries reappeared in France. An early level about 1700, equipped with a telescope, A.M. 191, by "Gio. Rodella Regio Macchinista, Padoua" is shown in the back of the cabinet of Fig. 56. A level by "Meurand A Paris 1788", A.M. 190, in all essentials like that of Antoine Chézy[25] (1718-1798), engineer and director of l'École des Ponts et Chaussées, and called by him a "niveau de pente" is shown in Fig. 62. This is equipped with movable pinnule and crosswires, the forerunner of stadia wires.

The last geodetic instrument on which comment will be made is one which might equally well be used in astronomy, a quadrant by "DuBois a Paris aux Genies," A.M. 439 (Fig. 63). It has levelling screws, motions in both altitude and azimuth with tangent screws and verniers.

The Collection has many alidades: by "Pigeon a Lyon," "Fabris Bovolente," "Giuseppe Stefani"; clinometers; scales of various sorts including some very interesting standard ells from various cities, whose variety emphasizes the importance of a Bureau of Standards.

Mathematical Instruments. The Museum contains a large assortment of mathematical instruments for measurements of various sorts, for drawing, for mapping, etc. Samples to illustrate the variety are presented in Fig. 64. Here are seen calipers; reduction compasses; proportional compasses (Galileo

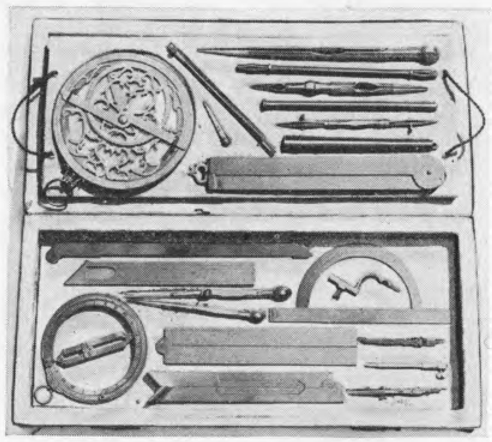


FIG. 65. A.M. 49. A SET OF OBSERVING AND DRAWING INSTRUMENTS WITH PIECES BY BUTTERFIELD, BOS, PIGEON.

[25] Laussedat, loc. cit. p. 295, Fig. 101.

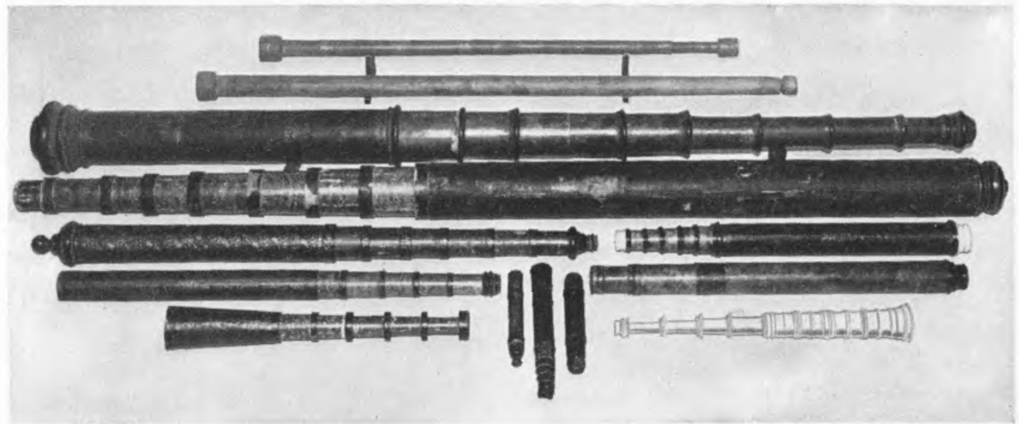


FIG. 66. A GROUP OF OLD TELESCOPES.

is often called the inventor but they go further back, to Commandino of Urbino 1568, or Guidubaldo del Monte); very useful three legged compasses, unfortunately now little used; parallel rulers; range finders using the cross-staff principle; a beautiful set of miniature drawing tools in silver by "Chapotot a Paris" (c. 1700—an associate of Jean Picard); a pedometer by Willebrandt; ellipsographs; trammel bar by "Dominicus Lusuerg F. Romae 1699," to be used with a cross in drawing ellipses; and a semicircular diopter and quadrant in its leather case inscribed "Capitan Petrv Spera Deo" (South German c. 1580).

In Fig. 65 is shown a set of instruments, A.M. 49, by Butterfield, an Englishman who worked in Paris between 1670-86. The pieces are not all of his construction: the astrolabe, A.M. 33 A, is signed "Ioannes Bos. I(nvenit) 1597 die Martii," the collapsible square at the bottom of the box is by "Pigeon A Paris," the protractor by "Jacobus Lusuerg Mutinensis (of Modena) 1672." The square by Pigeon is one of the most skilfully executed pieces of the entire

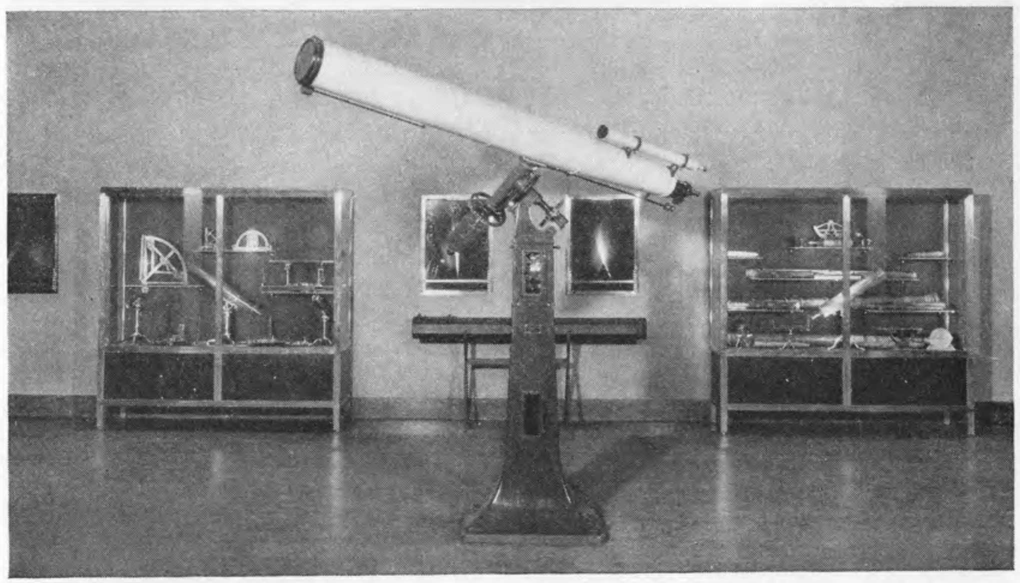


FIG. 67. SOUTH MUSEUM HALL WITH CABINETS OF TELESCOPES AND GEODETIC INSTRUMENTS, HERSCHEL'S 6-INCH TELESCOPE, AND MODERN REFRACTOR.

Collection, the joints are scarcely discernible.

Telescopes. The telescope is the most important instrument of astronomy. Its origin is obscure. It would seem that Roger Bacon (1214-1292) must have seen a telescope either at home or abroad, or have made one, for he wrote:[26] "Glasses or diaphanous bodies may be so formed that the most remote objects may appear just at hand . . . that we may read the smallest letters at an incredible distance." Also, there can be little doubt that Leonard Digges in 1550 or thereabouts, after study of Bacon, made "perspective glasses" wherewith he was able "to discover every particularité in the countrey rounde about." It is of interest to read that Thomas Harriot (1560-1621) mathematician and philosopher, "tutor of Sir Walter Raleigh and correspondent of Kepler," used a "perspective glass" in Virginia when he accompanied Sir Richard Grenville's expedition in 1585. Digges, who died in 1570 and who has already been cited as the maker of the theodolite, may have made reflectors as well, for this use of concave mirrors is revealed in writings of the time. The Dutch claimants to the invention of the telescope, Hans Lippershey, Zacharias Jansen, and James Metius, date from 1608. The serious use of the telescope in astronomical observation must be ascribed to Galileo who in 1610 made the first great telescopic discovery, the four brightest moons of Jupiter, an epoch-making event in the history of astronomy and of world history, an observation revolutionary in its effect on the course of human thought.

Forty-one telescopes were obtained in the Mensing Collection, of which five are reflectors. About a third of the refractors are incomplete, lacking either the objective or ocular. The reflectors, however, are complete, ready for use. For the most part the refractors are constructed with a series of draw tubes. The materials of the tubes are wood, metal, ivory, or paper; the latter in general being covered with parchment or leather finished plain, shagreen, or beautifully tooled. The makers of some of the

[26] Bacon, Epist. ad Parisiensem.

FIG. 68. A.M. 435. A REFLECTOR PROBABLY MADE FOR LOUIS XV.

telescopes are immediately ascertainable by signatures engraved on the tubes, for example:

A.M. 422 Initials "A. G." (c. 1650) Focal-length, 1.18 m.
A.M. 424 "John Marshall, Lutgat Street: London" (c. 1680) F, 2.98 m.
A.M. 434 "Passemant Rue de la Monnoye A La Pomme Dor A Paris." (c. 1740) F, 1.7 m.

Others have names etched on the objectives, a practice which should be adopted by modern opticians:

A.M. 426 "Pierro Patroni in Milano," (c. 1660) F, 2.07 m.
A.M. 431 "Francus Baillon fec. Mediolani (Milano) 1738" F, 1.70 m.
A.M. 442 "George Lepere, Quai de l'Horloge du Palais 1744"

The group of telescopes in Fig. 66 has, at the top, replicas of the first telescopes of Galileo. The originals are in the Tribuna di Galileo in Florence. The replicas were prepared by the Curator Giulio Cipriani of that city. The two great telescopes just below, A.M. 428 A and 428, have focal lengths of 5 m and 5.75 m respectively, apertures 6.8 cm. One of them has been

identified tentatively as a Campani. The telescopes of this optician won fame by the discovery with their use of the third and fifth and fourth satellites of Saturn, in the years 1672 and 1684.

The longer of the two telescopes below the Campani is A.M. 427. It is probably French though Mensing notes that the decoration suggests Torino. It is dark green Morocco, beautifully tooled with vignettes and lioncels in hundredfold repetition. It must have been made for a person of importance entitled to a coat-of-arms as indicated by the heraldic lioncels. Focal-length is 2.13 m. Its date is the latter part of the seventeenth century.

The conical telescope in the left foreground, A.M. 421, is one of the most important pieces in the entire Museum. Optically, it is of the Galilean type. The decoration places it in France at about 1630. It is one of the oldest intact telescopes in existence. The leather is beautifully tooled with gold figures of vines and flowers and birds. There are five draw tubes; the aperture is 2.5 cm, the focal-length 69 cm.

The conical companion to the right, A.M. 423, is of ivory, most delicately carved.

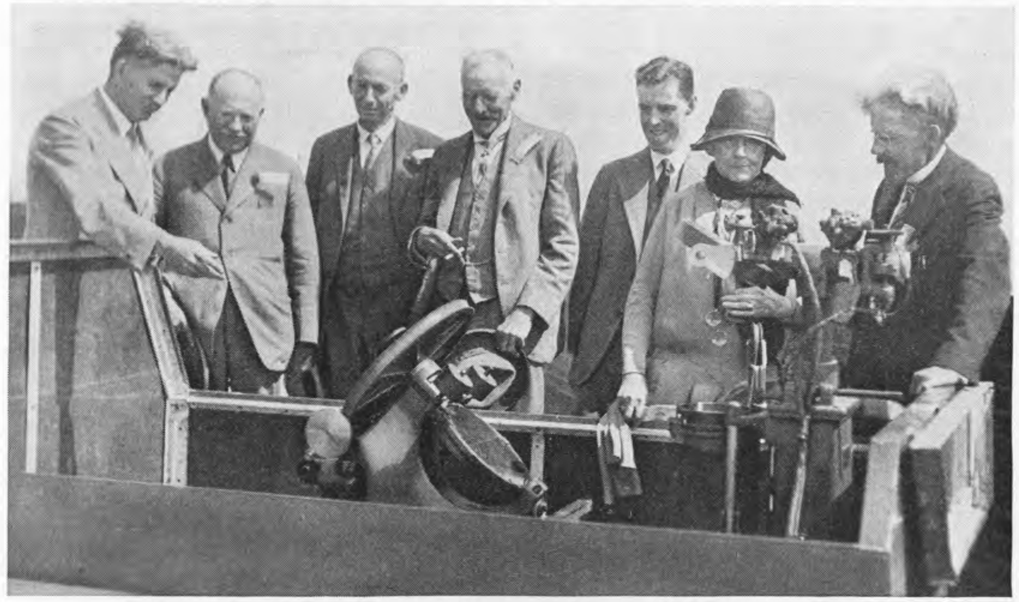


FIG. 69. COELOSTAT ON THE UPPER TERRACE.
Left to Right: Fox, Miller, Dugan, Brown, Schalen, Miss Cannon, Stewart.
Meeting American Astronomical Society, September 1930.

There are five draw tubes which permit an extension to 87 cm.

The cabinets for the display of the telescopes and certain geodetic instruments are shown in Fig. 67. In the center of the cabinet to the right is a reflector of extraordinary beauty, A.M. 435, which is shown singly in Fig. 68. It is richly embossed in silver ornaments of the Zodiacal figures and acanthus leaves and fleur-de-lis, probably made for Louis XV (1710-1774). The aperture is 100 mm, the length of the tube 77.5 cm. The speculum is very bright. A practical test of the instrument shows very satisfactory performance.

Fig. 67 shows also two large telescopes —a modern 8-inch refractor with lens by Alvan Clark & Sons, with a modern equatorial mounting by William Gaertner, a loan from the President of the Chicago Astronomical Society, the distinguished architect, Mr. Richard E. Schmidt; and in the background one of the chief prizes of the Museum, a 6-inch reflector by William Herschel. The latter is complete with speculum. This is a much appreciated gift from the British Admiralty through the kind offices of the Astronomer Royal, Sir Frank

Dyson. No piece in the museum receives more eager attention from visiting astronomers.

The Museum has a 4-inch Steinheil, gift of Mr. Oscar G. Mayer; a 5-inch Mellish; a 3-inch Vion; a 4-inch Mogey, and a 4-inch Zeiss, loaned respectively by Mr. H. S. Rich and by Carl Zeiss Inc. These may be carried into the open on the upper terrace for observation of the sky.

The Museum contains also the mounting and tube of Burnham's famous 6-inch refractor and the original mounting of the 18½-inch refractor of the Dearborn Observatory. These two items are of especial interest in Chicago. With the 6-inch, Burnham began his productive labors on double stars in Chicago, discovering 451 pairs with its use. This is loaned to the Museum by the Washburn Observatory of the University of Wisconsin. The 18½-inch Clark refractor erected in Chicago in 1865 on the campus of the original University of Chicago in Douglas Park and later transferred to Northwestern University in Evanston, was from its erection until 1876 the greatest refractor in the world. Truman Henry Safford, S. W. Burnham, Elias Colbert, G. W. Hough, and the writer, as successive directors of the observatory, used this telescope in its original form. It was given a new Warner & Swasey mounting in 1912. The old mounting, now erected on the lower floor, is a gift of the Chicago Astronomical Society.

The discussion of telescopes cannot be concluded without mention of the model of an observatory, shown in Fig. 29; the model of the top of Mount Wilson; the Meridian Circle of the Harvard College Observatory here on loan; and the coelostat and vertical telescope which bring a solar image into the corridor to the spectrohelioscope. The observatory model is based on the U. S. Naval Observatory in Washington, D. C., with the offices omitted, a building of excellent architectural design by R. M. Hunt. The model has a rotating dome, rising floor, and moving telescope. With one pressure of a button the dome moves, the telescope swings to a pointing in the slit, and the floor comes to proper adjustment. The dome is transparent so that the operation can be seen from all sides. The model of the top of Mt. Wilson with the many telescopes, laboratories, etc., constructed by Mr. Ferdinand Ellerman, is on loan from the Carnegie Institution of Washington. Its dimensions are 36x70x16 inches.

The coelostat and vertical telescope by William Gaertner is on the upper terrace (Fig. 69). Its mirrors are of pyrex. They throw the sunlight to a 6-inch lens of 20 feet focal-length of the vertical telescope. Used with the spectrohelioscope it is the one instrument of primary research of the institution. The lens may be moved aside to permit a vertical beam of parallel light to fall on the objectives of two small telescopes suspended in the museum halls below to give a large projected image of the Sun and the solar spectrum.

Mementoes of two astronomers of the last generation whose characters and careers were such that they shall be legendary, attract appreciative attention, like that accorded to Herschel's telescope. Few men of science have caught the popular fancy and at the same time the admiration of scholars in measure comparable to the two great astronomers who for so many years worked side by side at the Lick Observatory and later at the Yerkes Observatory, Sherburne Wesley Burnham and Edward Emerson Barnard—so alike in their unswerving devotion to observing, to whom a clear sky and a telescope meant opportunity and obligation. Burnham, excelling in everything he undertook, an expert rifle shot, artistic photographer, a speed stenographer, a figure of international renown in science while still employed as a clerk in the Federal Court, modest in all things, charitable but despising sham, a rare friend to many people, keen of vision, orderly in his routine as the stars themselves, working swiftly with economy of time, devoting his attention almost exclusively to double stars, accomplishing in observing and in the compilation of his General Catalogue of Double Stars one of the greatest pieces of work in practical astronomy the world has seen. Barnard, who entered astronomy by way of a photographic apprenticeship, worked through hardship and poverty to rank as

one of the greatest observers of all time, who built a house with prize money awarded for discovery of comets, whose eye first saw the fifth satellite of Jupiter, whose interest covered all phases of observing visual and photographic, of childlike simplicity and enthusiasm, with will of steel to hold his vigil through bitter cold.

Burnham's sons and daughters have deposited here his barometer, protractor, planimeter, an arithmograph which he designed and which was made by E. Kandler & Co. of Chicago, a circular slide-rule which he computed and which was built by Warner & Swasey at Cleveland, Ohio, a daguerreotype of him and his sister when he was sixteen years old, a miniature as he was in his eighty-first year, a gold medal received as a photographic award, and his gold medal from the Royal Astronomical Society, the great manuscript copies of his Catalogue of Double Stars. Mention has been made elsewhere of the tube of his 6-inch telescope.

The Yerkes Observatory of the University of Chicago has loaned for exhibition nine medals awarded to Edward Emerson Barnard for astronomical discoveries: Three bronze medals, the Donohoe Medal of the Astronomical Society of the Pacific for the discovery of Comets, 29 March 1881, 2 October 1891, and 12 October 1892; three gold medals from the Institut de France, Academie des Sciences,— Prix Lalande, 1892, Medaille Arago, 1893, Prix Janssen 1900; Gold Medal of the Royal Astronomical Society 1897; Prix J. Janssen, Societe Astronomique de France 1906; Catherine Wolfe Bruce Gold Medal of the Astronomical Society of the Pacific 1917.

The Yerkes Observatory of the University of Chicago has loaned also the radiometer built by Ernest Fox Nichols and used by him at the Yerkes Observatory in the first detection of the heat of the stars. With a similar instrument, in collaboration with Gordon Ferrie Hull, he later detected the pressure of light.

It is customary in some countries to strike medals in recognition of notable scholarly achievements or as award for attainments. The cabinet holding Burnham's and Barnard's medals contains also a collection of medals principally from the French national collection. Among them—Newton —Law of Universal Gravitation; Leverrier —Discovery of Neptune; Cassini—Foundation of the Paris Observatory; Franklin—Lightning from the Clouds; Janssen-Lockyer—Observation of Solar Prominences with Spectroscope; Hind-Luther-Goldschmidt—Discovery One Hundredth Asteroid; Measures of Meridian Arcs, Ecuador and Labrador; large portrait medallion of François Arago (1786–1853), French astronomer, geodesist, physicist, academician.

Meteorites have an appropriate place in an astronomical museum. They are the only heavenly bodies which can be put on exhibition in tangible form. Mr. Moise Dreyfus of Chicago has presented a small stony meteorite to our cabinets. No attempt has been made to assemble further specimens, for the neighboring Field Museum has a superb collection and effort for the study of these bodies might be spent more profitably toward the enrichment of that collection than in beginning a new one.

Ground Floor Museum Hall. The museum corridors of the main floor have been devoted to the display of antique instruments and astronomical photographs in the form of transparencies. On the lower floor more modern equipment is exhibited. One booth contains apparatus illustrating dynamical principles: Foucault pendulum of the Longdon type, to show the rotation of the Earth; a Foucault pendulum with a fairly stiff wire suspension mounted on a globe which can be rotated at will, instantly illustrating the Foucault principle; a precessional globe; apparatus to show the conservation of angular momentum, the relation of oblateness to the speed of rotation, the Doppler-Fizeau principle; modern mechanical planetaria.

A booth has been arranged to show the bridge of a ship with requisite instruments of navigation and communication. For the equipment of this exhibit we are indebted for the most part to the U. S. Navy.

A booth exhibiting geodetic instruments, wherein are shown five important historic instruments from the Coast and Geodetic

Survey; a beautiful theodolite or universal instrument by Warner and Swasey; modern surveyor's transits and precision levels by Carl Zeiss, Inc. and Buff and Buff; and a level, plane table with requisite equipment, and a cut-away transit, which shows all details of construction, by Eugene Dietzgen Co.

Two booths are devoted to computing devices. Eugene Dietzgen and Keuffel & Esser display drawing instruments, protractors, scales, slide-rules, planimeters, integrators. Computing engines are exhibited: Comptometer, Burroughs, Monroe, Marchant, Sunstrand, Victor.

A booth is allotted to the Amateur Telescope Makers of Chicago where members may make and exhibit their instruments. Spencer Lens Co., Bausch and Lomb, and Carl Zeiss, Inc. have installed exhibits of small optical parts in various stages of the progress of manufacture. Mr. Carl D. Turner of Indianapolis has placed a 15-inch reflector, an electrically driven equatorial, on exhibition in this booth. To illustrate the possibilities of various non-tarnishing metallic surfaces for reflectors Mr. Robley C. Williams of Cornell University exhibits plane glass mirrors with the following metals evaporated from hot filaments: aluminum, chromium, indium, bismuth, tin, antimony, copper, gold. Aluminum seems to be highly promising and may displace the commonly used silver. A twelve-inch flat with aluminum surface exhibited by the California Institute of Technology reinforces this surmise. Mr. George H. Lutz has placed three stellite mirrors on exhibition to demonstrate the feasibility of utilizing all metal instead of metal on glass. A large grinding machine, gift of Carl Zeiss, Jena, is in operation in this booth.

A booth is utilized for a series of spectro-demonstrators to illustrate the various kinds of spectra with typical examples. Here also is mounted a model of Michelson's velocity of light apparatus built at the Mt. Wilson Observatory and loaned by the Carnegie Institution of Washington. A bronze bust of Michelson by Oscar J. W. Hansen stands in this booth.

A group of modern astronomical measuring machines occupies another booth. Gaertner Scientific Corporation displays a measuring engine for stellar plates such as are used for parallax determinations; one for stellar spectra; a Hartmann microphotometer; and a micro-densitometer. On a Zeiss flicker comparator copies of the discovery plates of Pluto from the Lowell Observatory are displayed.

The remaining booth is arranged to show the principle of Arcturus lighting the Fair. A telescope with a photo-electric cell, provided by the General Electric Company, is directed toward an artificial star. When a metal disk before the objective is drawn aside the light falls on the cell producing a feeble electric current which is amplified to throw a switch to turn on lights behind a silhouette of the Chicago skyline. Photo-electric cells made by R. J. Cashman and W. S. Huxford of the Physical Laboratory of Northwestern University and an amplifying tube by General Electric are displayed in this booth.

The original mounting of the Dearborn Observatory 18½-inch refractor mentioned above is erected in the center of the room. The meridian circle, also mentioned above, set up on this floor is directed to a moving artificial sky. Two chronographs, one a gift of the U. S. Navy, the other exhibited by the Gaertner Scientific Corporation may be used with it to show the method of recording time.

The lecture room on the ground floor serves as a meeting place for the Chicago Astronomical Society which has its headquarters at the Planetarium. This Society was founded in 1863. With the exception of the Royal Astronomical Society of London, it is the oldest astronomical society in the world. Under the present affiliation with the Planetarium, the Society is rapidly increasing its membership.

Library. As part of his original gift, Mr. Adler presented about two hundred books, a nucleus for an astronomical reference library. To these have been added about 500 volumes by gift. So far as purchases are concerned, the primary effort has been toward the acquisition of books on old instruments and their uses, such books for example as:

Apianus—Instrument Buch — Ingolstad 1533
Cosimo Bartoli—Del Modo di Misurare, Veneti 1614
Valer. Regnartius — Astrolabiorum — Bononia 1610
Mallet—La Geometrie Pratique—Paris 1702
Bion — Instrumens Mathematique — Paris 1725
Eg. Danti—Astrolabio—Fiorenza 1569.

In the last it is interesting to see in the introductory pages two poems by a member of the Strozzi family, Giouambatista Strozzi il Giouine (1551–1634).

> "Spirto divin ch'ergendo el Cielo il volto, . . ."

Of book gifts, the principal ones are: from Mr. G. H. Jones of Chicago 327 volumes from the library of Professor Elias Colbert including sets of Galileo, Kepler, Laplace, many old works, Manilius, Euler. From Mrs. George H. Mason, daughter of Professor Colbert, the "Phaenomena" of Aratus, 1589. From Mrs. W. O. Beal and sons 59 volumes from the library of Professor Beal including a set of Tisserand's "Traite de Mécanique Celeste"; British Astronomical Association, 25 volumes of their Journal; British Nautical Almanac Office, 15 volumes, 1920 to 1933; U. S. Nautical Almanac Office, 58 volumes, 1867 to 1933. From Mr. Richard E. Schmidt, President of the Chicago Astronomical Society, many volumes of The Observatory, L'Astronomie, and Popular Astronomy; and seven volumes of The International Critical Tables. Other donations to the library in the form of pictures, manuscripts, and books have been received from: Mrs. Edmond E. Blaauw, F. E. Brasch, H. C. Burnham, L. J. Comrie, Henry Crew, C. R. Fowler, Morton Hague, George E. Hale, Harvard College Observatory, Paul C. Hutton, C. O. Lampland, Mrs. Isabel M. Lewis, G. H. Lutz, J. J. Nassau, Jacob Olson, Harry Oppenheimer, Mrs. Dorothea K. Roberts, Rev. Luis Rodes, Morris Schanoes, James B. Stokley, Ambrose Swasey, University of Michigan Observatory, Frank J. Vassar, Miss Caroline Wicker, W. H. Wright, Yale University Observatory, and the Yerkes Observatory.

Transparencies. Photography is the most powerful aid to the telescope in astronomical research, with the cumulative action of long exposures, the accuracy and permanency of delineation, the wide field of the portrait lens, the registration of analyzed light in the spectrograph, it has marvelously extended the boundaries of knowledge of the heavens. At the same time, it provides the most vivid means of portraying the results. Nowhere has the Chinese proverb "One picture is worth a thousand words" better exemplification than in astronomy. Of the various possibilities of photographic display, illuminated transparencies are the most accurate as well as the most brilliant.

Seventy-two large transparencies from negatives made with the world's greatest telescopes are mounted in niches in the museum walls provided for this purpose in the design of the building. The North and South Museum Halls each contain eighteen transparencies, size 24x30 inches, the East Corridor, thirty-six of size 17½x24 inches.

Those of the South Hall are devoted to the Solar System, with distribution of subjects as follows: on the inner wall (Fig. 1), six of the Moon logically arranged, including an 8½-day, a 16-day, an 18-day Moon and three enlarged portions, the regions of Tycho, Archimedes, and Copernicus. On the outer wall: five of the Sun—two coronae, a direct photograph of the disk, a spectroheliogram in hydrogen and one in calcium; seven of comets—four of Morehouse' Comet, showing changes, one each of Halley's, Brook's, and 1910*a*.

In the East Corridor the Solar System subjects include six on sections of the solar disk, one disk and prominence, and three of prominences; nine of planets. In addition, there are two for the greatest telescopes of each type; two for their housings; one portrait; one of star trails; nine of clusters, novae, and nebulae; and two of stellar spectra.

The transparencies of the North Hall are devoted entirely to the Sidereal System. The six transparencies on the inner wall are of the Milky Way from negatives by Barnard and Ross. On the outer wall, seven are of galactic nebulae, three of spirals, and two of the Magellanic Clouds.

Immediately below each transparency there is a legend (see Fig. 67) in transparency negative form, white letters on black field, which gives such explanatory material as can be included within the limits of the space, always including the name of the astronomer who took the photograph, the instrument, date, and exposure time where pertinent.

When the transparencies were made, a few extra were provided that some change of display could be made from time to time. The following observatories are represented: Yerkes, Mount Wilson, Lowell, Lick, Harvard College, University of Michigan, Dearborn, Georgetown College, Greenwich, and Meudon.

The transparencies from the Mt. Wilson and Lick Observatories were made by Mr. Ferdinand Ellerman of the Mt. Wilson Observatory, whose well-known photographic skill is sufficient guarantee of their quality. The Lowell Observatory transparencies were made at Flagstaff by members of the observatory staff. Extraordinary pains were taken in their preparation, especially the composite plate of Mars with fifteen exposures from as many negatives showing the seasonal variation of the polar cap. The transparencies from the Yerkes, Michigan, Harvard, and Dearborn Observatory negatives were made by Mr. Charles A. Crowell of Chicago. Taken as a whole these superb pictures tell with graphic emphasis the story of astronomy's view of the universe.

The interest of the public in the Planetarium and Museum has been very gratifying. The attendance during the first year was 731;108. The million mark was passed on the 479th day. The average daily attendance for the first two years was 1704. No record is available to show how many of the total have made more than a single visit. Certain it is that there are many who come frequently and many who announce that they are attending each month to hear the complete cycle of lectures, some oftener than once a month. The large attendance is the more gratifying when it is realized that the building is more than a mile from street car or elevated transportation: only busses and taxis are available for public conveyance. Moreover, until 1933 the approach to the building was none too inviting. The way to the island lead across the lagoon by a temporary wooden bridge, which in rough weather might be swept by waves, and then a bleak third of a mile on a dirt and cinder road or path. The great bridge, the landscaping, and the approach esplanade (by the National Terrazzo and Mosaic Association) have totally changed this aspect. During the first hundred days of A Century of Progress Exposition 550,000 visitors attended the demonstrations. The daily attendance during the last half of August has averaged over 10,000.

Here is a museum devoted to the noblest aspiration of man's mind, the understanding of the universe. Here he may let his mind grope outward into limitless space nor remain forever earthbound, shrinking the universe to his petty stature. Better be again a clod of clay of that Earth from which he came than never to have risen to the height from which the wide vision of creation may be obtained and have felt that glorious exaltation of him who cried:

"Then felt I like some watcher of the sky."