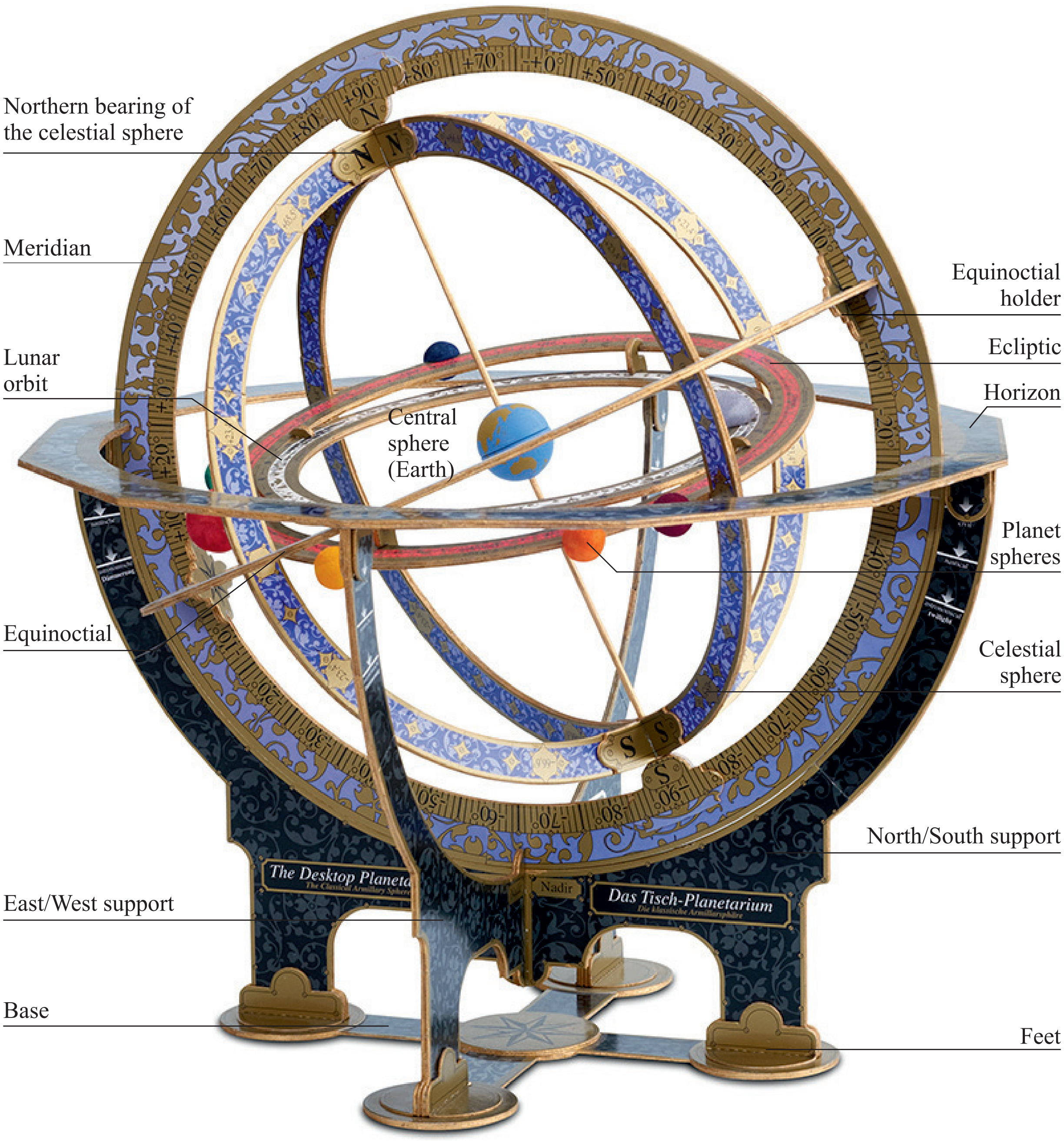
KLAUS HÜNIG

The Desktop Planetarium

Instructions for construction and use



AstroMedia

Hands-on Science Series

Article No 832.TPL-E · Made in Germany

The Desktop Planetarium

With this armillary sphere, one of the most important astronomical instruments, AstroMedia is continuing a tradition that reaches back several hundred years. The name comes from the Latin "*armilla*", which translates as bracelet or ring. Armillary sphere therefore means "sphere made from rings". You could describe it as a celestial globe that has been reduced to the astronomically relevant rings.

The armillary sphere was first mentioned around 300 BC in the texts of Greek astronomers, but was probably already in use much earlier in Babylonia. In China it was known for at least 2000 years. In Arabia it was called âlat dât al halaq ("instrument with the rings") and stood in very high regard. To increase their accuracy, they built them as large as possible: in Cairo stood an armillary sphere with a diameter of 5 meter!

Until the 16th century it remained the most important instrument for observation, calculation, and explanation of the position of celestial bodies. With the Dane Tycho Brahe (1546-1601), the last great astronomer before the invention of the telescope, the armillary sphere reached its peak in the form of large ring instruments and could hardly be improved anymore.

In the following centuries its didactical merits were still in high regard, but when planetarium projectors and astronomy software for computers became widely available, the armillary sphere was nearly forgotten. Nowadays more and more people rediscover the advantages of real, tactile teaching tools over virtual ones. This also lead to the rediscovery of the armillary sphere as the ideal instrument to become acquainted with celestial movements and understand day and night sky from an observers viewpoint. Since 1993 AstroMedia has been developing new armillary spheres again, called "Desktop Planetariums", that are loved not only by amateur astronomers, teachers, and lecturers. They have turned AstroMedia into one of the largest producers of armillary spheres in the world.

The parts of this Desktop Planetarium, like support, meridian, celestial sphere, ecliptic, equinoctial, and lunar orbit are constructed from four layers of sturdy cardboard and have therefore nearly the stability of laminated wood. Sun, Moon, and the five classical planets are represented by foam rubber balls, that can be stuck to any position on the ecliptic or the lunar orbit. The lunar orbit itself is tilted by 5.2º against the ecliptic and has adjustable nodes: a new improvement of the centuries-old armillary sphere, developed by AstroMedia!

Contents:

16 pre-punched sheets of cardboard, 0.65mm
3 wooden axles, 150 x 2.5mm (celestial axis, 1 reserve)
3 PVC discs, ø 8 x 2.7mm, 0.5mm thick (celestial sphere bearings, 1 reserve)
2 wooden hemispheres, ø 25mm, with 2.5mm hole (central sphere)
4 metal pins, 13 x 1.25mm (ecliptic holders)
2 foam rubber balls, 20mm with slot (Sun and Moon)
5 foam rubber balls, 13mm with slot (Mercury, Venus, Mars, Jupiter, and Saturn)

You will also need for assembly:

A firm, even work surface.

Standard solvent based all purpose glue, e.g. UHU, Evo-Stik Impact, B&Q Diall All Purpose Glue. **Do not use water-based glue**: it softens and warps the cardboard, and doesn't stick properly to the printed surfaces. Solvent based glues also dry much faster.

A sharp knife with a fine point (thin carpet knife, craft knife, scalpel) to cut the thin holding tabs of the pre-punched parts. Also, a **sharp** pair of scissors for the cuts in the lunar orbit.

A cutting board or mat, made from hardboard, plastic, or wood. Self-healing cutting mats are ideal, as the material re-closes after each cut.

A piece of sand paper or a file of our file set (400.SBF) to clean or file cardboard edges.

Some clothes-pegs to temporarily hold freshly glued joints.

For the collapsible version: a screw driver to tighten the barrel bolts.

Coloured felt pens or model paint and brushes to paint the planets (e.g. yellow - Mercury, green - Venus, dark red - Mars, orange - Jupiter, purple - Saturn, light red or gold - Sun, white or silver - Moon).

Optional: A golden lacquer pen to paint the white edges of the constructed parts and make them match the printed surfaces, also for the Sun (if not painted light red), the celestial axis, and the central sphere (if not painted like a globe). You can also use narrow gold-coloured tape as used for pinstripe lines on car bodywork to cover the edges.
Maybe also a silver lacquer pen for the Moon (if not painted white).

Optional: blue, white, and brown paint for the central sphere if you want to paint it as a mini-globe with land masses, oceans, polar ice caps, and clouds.

Important preliminary note: GLUED or COLLAPSIBLE?

You have the choice of constructing the planetarium permanently glued together or collapsible, so that you can store it flat; e.g. if you want to transport it to different venues for teaching or lectures. For the collapsible version you need a set of 18 so-called barrel bolts made from brass, with a shaft length and diameter of 5mm. You can order those directly from your AstroMedia supplier (article number 434.BUS). **You need to decide which version you want to build before you commence, later changes are not possible**.

Most parts are identical for both versions. Parts that are only meant for the glued version bear a number beginning with "v-". The numbers for the collapsible version start with a "z-". The instructions for the two versions are different too: For the glued version use the parts marked in green, for the collapsible version use the red ones. Nevertheless, the larger part of the instructions are the same for both versions and are marked in grey.

Tips for successful construction - Please read before commencing!

In order to ensure good results and for straightforward construction, the building instructions have been broken down into Chapters A to X, which are broken down further into 82 smaller steps. Do not be worried by the long text - it is simpler and faster than it appears and helps to avoid mistakes. Read each step from the beginning to the end before commencing and allow yourself about 8 to 12 hours for the construction (depending on experience). The more care you take, the better your Desktop Planetarium will work and look.

Every part has its name (in German) and/or part number printed on the front and back. The part number consists of a letter and a number: the letter denotes the chapter it belongs to, the numbers denote the order of construction. The part number can be recognised by its rectangular frame, e.g. C1 , v-R5 , z-R5 . In the instructions part numbers are given in rectangular brackets, e.g. [C1], [v-R5], [z-R5]. Only remove the parts as you need them.

Places needing glue are marked in grey. On each of these grey areas you will find a part number printed in italic followed by an arrow in a square: **C14** ⟶▸ The number denotes the part (or tab of the part) that will be glued in this place. If the glue area is filled with grey dots instead of being completely grey, glue is only applied here for the non-collapsible version! Please keep in mind that the glueing areas are slightly smaller than the parts that will be glued to them. This ensures that grey areas will be completely covered.

Nearly all parts of the planetarium are constructed from four layers of cardboard, which gives them the stability of thin laminated wood. Larger parts are constructed from overlapping pieces.

We recommend that you do not tear the parts out of the cardboard sheet, but cut through the thin connecting tabs to make sure that the edges stay smooth. Frayed edges can be cleaned with sandpaper or with our AstroMedia File Set (400.SBF). If you want to paint the edges golden, you should do so before fitting them into their final position.

Only for glued version: The 5mm holes in many of the parts should not be opened. Leave the small cardboard disks inside them in place.

Only for collapsible version: The 5mm holes in many of the parts have to be opened before fitting the parts. They will later take the barrel bolts.

We recommend that larger parts that are glued on top of each other are pressed against an even surface while the glue sets to make sure that they don't warp.

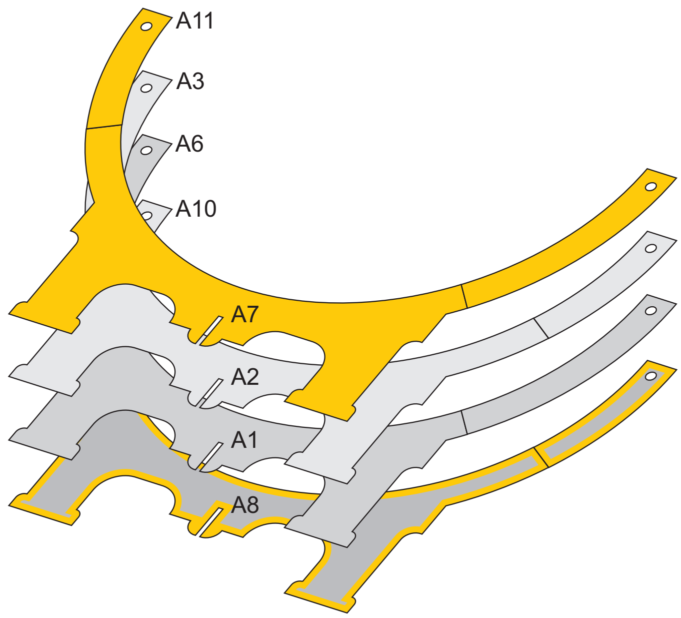
All folding lines are prepared by perforations. If they are to be bent "forwards", you have to fold them towards you when looking at the gold printed side of the part. If they are to be bent "backwards", you need to fold them away from you. You get a straighter fold if you position the folding line over a sharp edge.

Building Instructions

Chapter A

The North/South Support

The horizon frame of the Desktop Planetarium consists of a cross-shaped, flat base carrying two stands crossed at right angles, and the horizon, which is fitted to the top of those. The stand that is fitted to the north and south points of the horizon is called the "north/south support". It can be recognised by the fact that it has an uninterrupted semi-circular inner edge that will later support the meridian ring. The other stand is the "east/west support". It has a small semi-circular protrusion with a slit at the lowest part of the inner edge, which will act as a guide for the meridian.
As most parts of the Desktop Planetarium, the supports consist of four layers of cardboard: The two inner layers are glued together front against front, the two outer layers are then glued onto those with the printed sides facing outwards.



Step 1: Glue the two inner parts of the north/south support [A1, sheet 15 + A2, sheet 16] flush on top of each other, with the front sides facing each other. The parts are asymmetrical, so there is a tag protruding on each side.

TIP: *Make sure that you really glue the inner parts front against front and not by mistake back against back. This is important because it ensures that the parts will overlap properly (like brickwork), which gives the finished part its strength. If you follow the glue symbols and part numbers, you can't go wrong. You can also recognise the front side of a sheet of cardboard by looking closely at the cuts: since they are made from the front, they are wider on the front and narrower on the back.*
Remember to remove the small 5mm disks from the parts if you want to build the collapsible version!

Step 2: Glue the inner arm 1 [A3, sheet 5] onto the respective glue mark on the inner support part 2 [A2]. Its end should be lying flush against the end of support part 1 [A1] without a gap. The other end is now protruding outwards. Turn the support over and glue the inner arm 2 [A4, sheet 6] in its place. Its upper end will protrude as well.

TIP: *Feel along the edges before the glue sets and check that all parts are completely flush.*

Step 3: Turn the support over again and glue the inner arm 3 [A5, sheet 15] onto the protruding end of the just fitted arm 2 [A4]. Again it should fit without a gap and all edges as well as the 5mm holes for the collapsible version should be flush. Turn the support over again and fit inner arm 4 [A6, sheet 15].
The inner part of the north/south support is now finished and will now be covered with the outer parts.

TIP: *The remainder of the construction of the support is quite straightforward and although the glue marks prescribe exactly which part goes where, it doesn't matter if you ignore them in this case: The parts for the front and rear sides are identical and interchangeable.*

Step 4: Glue the outer part 1 of the north/south support [A7, sheet 13] onto one side of the inner support and the other outer part [A8, sheet 14] onto the other. The abutting edges of the inner part are covered in the process. Again make sure that all edges are completely flush. Finally glue the two long outer arms 1 and 2 [A9, sheet 1 + A10, sheet 2] as well as the two short outer arms 3 and 4 [A11 + A12, sheet 13] onto the free spaces of the inner support.

Chapter B

The East/West Support

The construction of the east/west support is the same as that of the north/south support. Apart from swapping the letter A for the letter B, the part numbers are identical.

Step 5: Glue the inner parts 1 and 2 [B1, sheet 15 + B2, sheet 16] front to front.

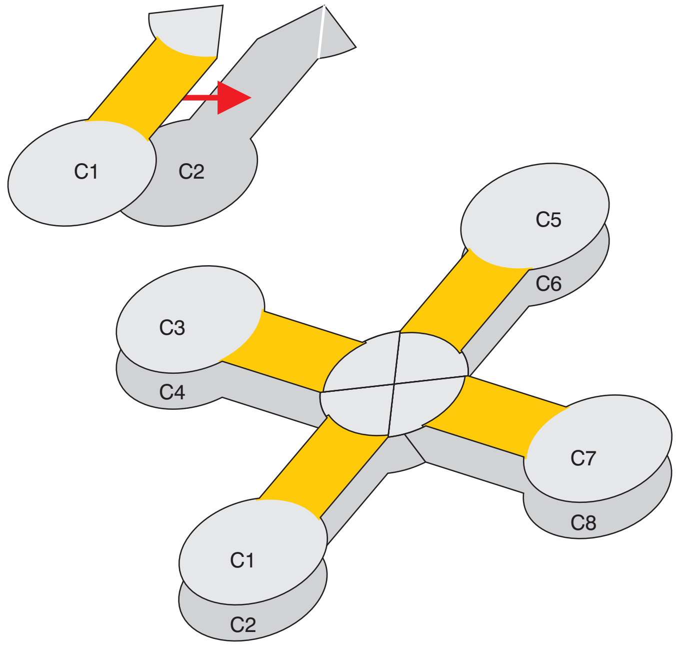
Step 6: Glue the two long protruding inner arms 1 and 2 [B3, sheet 7 + B4, sheet 8] onto their designated glue tabs on the inner support.

Step 7: Now glue the two inner arms 3 and 4 [B5 + B6, sheet 16] in place.
The construction of the inner part of the east/west support is now complete.

Step 8: Cover the inner part of the east/west support with its outer parts 1 and 2 [B7, sheet 13 + B8, sheet 14] as well as with the outer arms 1 to 4 [B9, sheet 3 + B10, sheet 4 + B11 and B12, sheet 14]. Let both supports dry thoroughly, best on an even surface with a weight on top, to make sure they reach their full stability and do not warp before carrying on.

TIP: *The glue might set slower than you think because it takes a while before the solvent escapes from between the layers. This is true for all parts of the planetarium that are constructed from four layers of cardboard.*

Step 9: After the glue has set, slide the two supports into each other. If the slots in the middle are slightly too narrow or too short, you can carefully widen or lengthen them a bit. The supports must stand evenly on all four legs without wobbling.



Chapter C

The Base

The base consists of four arms that are glued together to form a cross. In the centre and at the ends of the arms are circles that are reinforced with extra disks on both sides. The arms are made from two layers that differ slightly so that protruding tags are formed at one end. These are used to connect the arms and form the cross.

Step 10: Glue the upper and lower part of arm 1 [C1, sheet 1 + C2, sheet 5] back to back on top of each other. The arm now consists of two flush layers, only at the end that will form the centre circle are two protruding tags. In the same way construct arm 2 [C3, sheet 2 + C4, sheet 6], arm 3 [C5, sheet 3 + C6, sheet 7], and arm 4 [C7, sheet 4 + C8, sheet 8].

Step 11: Now glue the protruding tags of the arms together, each one on top of the next one, to form the cross with the circle in the middle.

Step 12: Glue the lower disks 1 to 4 [C9, C10, C11, sheet 15 + C12, sheet 16] onto the lower glue marks at the ends of the arms. Also glue the lower centre disk [C13, sheet 14] onto the middle of the cross.

Step 13: Turn the base over and glue the upper disks 1 to 4 [C14, C15, C16, sheet 13 + C17, sheet 14] onto the ends of the arms. The grey glue marks on the top of the disks have a grey dotted line. These lines should point towards the centre of the cross, i.e. they should be parallel to the arms. Also glue the three upper disks [C18 and C19, sheet 16 + C20, sheet 14] on top of each other and finally onto the middle of the base.
This concludes the construction of the base. Make sure that it stays completely flat and doesn't warp while the glue sets.

Chapter v-D

The Feet (glued version)

Like all green marked chapters, this one is only valid for the glued version. If you are building the collapsible version, please skip this chapter and carry on with the red marked Chapter z-D.
The feet connect the supports with the base. Two of them are first glued to each support leg and afterwards all together onto the base. The upper part of the feet that is glued to the legs is first reinforced with a second layer of cardboard.

TIP: *Although they are properly numbered, all 8 feet are identical, so it doesn't matter if you mix them up.*

Step 14: Fold the upper part of the feet 1 to 8 [v-D1 to v-D8, sheet 13 and 14] forwards along the perforation.

Step 15: Now cut away the semi-circular lower parts of all foot parts 9 - 16 [v-D9 to v-D16, sheet 15 and 16] and glue the remaining upper parts flush behind the upper parts of feet 1 to 8.

Step 16: Glue the north/south and the east/west supports together along their connection and check again that the resulting horizon support stands evenly on all four legs.

Step 17: On one leg first, glue a foot on each side, so that the round sides on the upper parts are flush with the rounding on the leg. The hole in the leg (in case you removed the little disks) is now covered and the lower parts of the feet should lie flat on the work surface. The lower edge of the leg should stand on the work surface as well. Now glue the other feet onto the other legs in a similar manner.

Step 18: Put the horizon support onto the base, so that the feet are in the centre of the upper base disks [C14 to C17]. Glue the support into this position.

Chapter z-D

The Feet (collapsible version)

Like all red marked chapters, this one is only valid for the collapsible version. For the glued version please refer to the green chapters.
The feet connect the supports with the base. Two of them are first connected to each support leg by a barrel bolt and afterwards glued onto the base. This way, the support can always be removed from the base. The upper part of the feet that has the hole is first reinforced with a second layer of cardboard.

TIP: *Although they are properly numbered, all 8 feet are identical, so it doesn't matter if you mix them up.*

Step 14: Fold the upper part of the feet 1 to 8 [z-D1 to z-D8, sheet 13 and 14] forwards along the perforation.

Step 15: Now cut away the semi-circular lower parts of all foot parts 9 - 16 [z-D9 to z-D16, sheet 15 and 16] and glue the remaining upper parts flush behind the upper parts of feet 1 to 8.

Step 16: If you haven't already done this, slide the north/south and the east/west supports together along their connection slots and check again that the resulting horizon support stands evenly on all four legs.

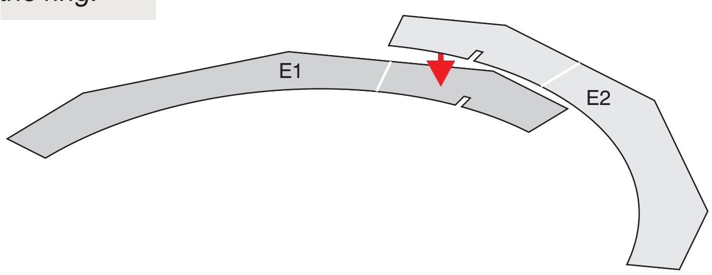
Step 17: On one leg first, fit a foot on each side using a barrel bolt, so that the round sides on the upper parts are flush with the rounding on the leg. Before fully tightening the bolt, make sure that the lower edge of the leg and the lower parts of the feet are flat on the work surface. Now fit the other feet to the other legs in a similar manner.

Step 18: Put the horizon support onto the base, so that the feet are in the centre of the upper base disks [C14 to C17]. Glue the semicircular parts of the feet into this position on the base, taking care that no glue reaches the legs of the support.

Chapter E

The Horizon

The circular horizon is also constructed from 4 layers of cardboard. Each layer consists of four separate parts. Again, as before with the supports, the two inner layers are glued together with their <u>front sides facing each other</u> and because they only overlap partly, a part of them will always protrude. Again take care that all edges are completely flush and the parts abut without a gap. This is important to make sure that the last elements fit properly to complete the ring.



Step 19: Glue the horizon inner parts 1 and 2 [E1, sheet 5 + E2, sheet 6] together on their designated glue marks with their front sides facing each other. The edges as well as the rectangular cutout have to be exactly flush. The two parts only overlap on one third of their length, two thirds are protruding on each side.

Step 20: Glue the inner part 3 [E3, sheet 5] onto its glue mark on part 2. This time the parts overlap on two thirds of their length and only one third protrudes. Onto this part you now glue inner part 4 [E4, sheet 6]. Now there are again two thirds protruding, onto which you glue inner part 5 [A5, sheet 7].

Step 21: Carry on in the same manner, fitting inner parts 6 to 8 [E6, sheet 8 + E7, sheet 7 + E8, sheet 8]. The last part 8 [E8] is glued to part 7 [E7] and part 1 [E1] and therefore closes the two-layered ring of inner parts.

Step 22: Now glue the upper horizon parts 1 to 4 [E9 and E10, sheet 1 + E11 and E12, sheet 2] onto their respective glue marks on the inner horizon ring. Check that the degree markings run properly around the ring in clockwise direction. The "N" and "S" markings should lie at the spots where the horizon ring has a cutout on its inner edge. The cutouts will later guide the meridian.

Step 23: In the same manner glue the lower horizon parts 1 to 4 [E13 and E14, sheet 3 + E15 and E16, sheet 4] onto the lower side of the ring.

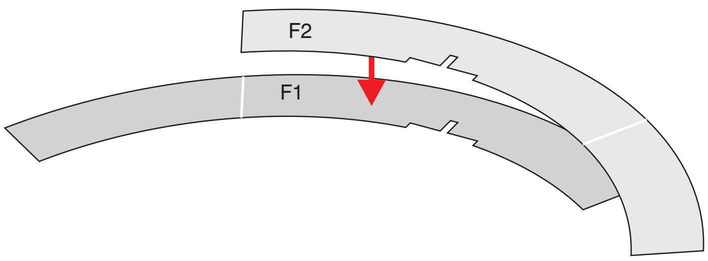
Check that the horizon fits onto the horizon support. The two cutouts should lie exactly above the two arms of the north/south support (the one with the continuous semi-circular inner edge). The cutouts and the inner edge of the support will later guide the meridian.

We will first construct the meridian and check its fit before connecting the horizon to its support.

Chapter F

The Meridian

The meridian is also made up of four layers of cardboard, which in turn consist of four overlapping parts each. Again the inner two layers are glued together with their front sides facing each other. Take care that all edges are completely flush and that they abut without a gap, so that in the end you have a perfect circle.



Step 24: Glue the meridian inner parts 1 and 2 [F1, sheet 5 + F2, sheet 6] together on their designated glue marks with their front sides facing each other, as depicted. Both parts have a cutout on their inner edge that will later receive the equinoctial. Make sure that these cutouts are exactly flush. The parts overlap on two thirds of their length, one third protrudes on each side.

Step 25: Remove the inner axle holder [S1] from the meridian inner part 3 [F3, sheet 5] and put it aside. *Hint: the axle holders will later take the wooden celestial axis at the end of the construction.* Now glue the inner part 3 onto its designated glue area on part 2 [F2]. This leaves two thirds of part 3 protruding.

Step 26: Remove the inner axle holder [S2] from the meridian inner part 4 [F4, sheet 6], and put it aside with the other one. Then glue the inner part 4 onto part 3. Take care that the cutouts that held the axle holders are completely flush.

Step 27: Carry on in the same manner with the inner parts 5 to 8 [F5 and F7, sheet 7 + F6 and F8, sheet 8] to form the complete ring.

This completes the inner two layers of the meridian ring. Now you need to glue the outer layers, that carry the degree scale, onto its surfaces. To make things easier they will be called "upper" and "lower", although the meridian ring is later standing upright inside the planetarium.

Step 28: Remove the upper meridian parts 1 to 4 [F9 and F10, sheet 1 + F11 and F12, sheet 2] from the cardboard sheet and put the axle holders aside. First put the parts in place without glue, which is quite straight forward because of the cutouts. Check that the degree scale is correctly formed: The positive numbers are on the northern half, the negative ones are on the southern half. Now glue the segments into this position.

Step 29: Repeat the last step with the lower meridian parts 1 to 4 [F13 and F14, sheet 3 + F15 and F16, sheet 4]. Again make sure that the positive degree numbers are on the northern half of the ring and the negative numbers on the southern half (in the same position as the ones on the upper side of the meridian ring). Let dry thoroughly.
Now lay the horizon ring onto the support so that the points marked "N" and "S" lie on the ends of the north/south support. Stand the meridian upright onto the north/south support, so that it is held by the cutouts in the horizon ring. Check that it can turn easily inside the cutouts. If they are too narrow or too short, you can widen them with a sand paper file or a sharp knife.
Now the horizon can be fitted to the support using the connection brackets.

Chapter v-G:

The Connection Brackets (glued version)

The connection between the four arms of the support and the horizon ring consists of eight connection brackets, two for each arm. The brackets are first glued to the support and afterwards to the horizon ring. Similar to the feet, the part of the brackets that is glued to the support is reinforced by an additional layer of cardboard. The brackets are numbered, but are actually identical and can therefore be glued in place in any order.

Step 30: Fold the brackets 1 to 8 forwards along the perforation [v-G1 and v-G2, sheet 1 + v-G3 and v-G4, sheet 2 + v-G5 and v-G6, sheet 3 + v-G7 and v-G8, sheet 4].

Step 31: Cut off the indicated half of the reinforcement brackets 9 to 16 along the perforation [v-G9 and v-G10, sheet 5 + v-G11 and v-G12, sheet 6 + v-G13 and v-G14, sheet 7 + v-G15 and v-G16, sheet 8]. Glue the remaining half of each bracket flush behind one of the brackets 1 to 8, to the half that has an arrow depicted on the front.

Step 32: Put the support upside down on your work surface, so that the base is on top and the arms stand flat on the worktop. Glue one bracket with its reinforced part on each side of every arm, so that the other part lies flat on the work surface. The holes in the arms will then be covered.

Step 33: Put the horizon ring with the degree scale downwards onto your work surface and stand the support upside down on top if it. The connection brackets are then standing on their respective glue marks on the underside of the horizon. Check that the north/south support (the one with the continuous semicircular inner edge) is standing on the parts of the horizon that have the cutouts for the meridian.

Step 39: Glue the two inner parts of bracket 1 [H17 and H18, sheet 11] back to back, and then the two outer parts [H19 and H20, sheet 9] on top of them. Repeat this step for the other two inner parts [H21 and H22, sheet 12] and the other two outer parts [H23 and H24, sheet 10] for the second bracket.

Step 40: Both brackets have a grey stripe across one side. First without glue, push the brackets into the shallow cutouts on the inside of the connections, so that the grey stripe lies on the inner edge of the equinoctial. Check that the brackets are fitting snuggly; if not, widen the small rectangular cutouts at their ends and try again. Separate the two rings again and glue the brackets into their position on the inside edge of the equinoctial. Don't put the equinoctial back into its place just yet.

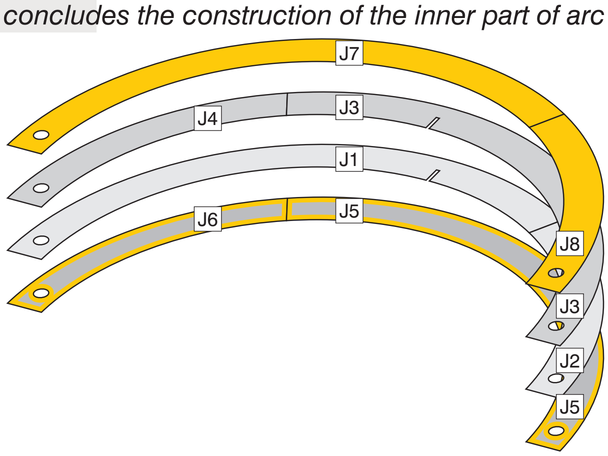
Chapter J

The Celestial Sphere, Arc 1

The celestial sphere consists of two interconnected rings at right angles. To accomplish this, we construct four semi-circular arcs that consist of four layers and which will be connected at their ends in the celestial sphere bearings (see Chapters N and O). Each layer consists of only two parts, one about twice as long as the other. Inside the completed rings of the celestial sphere we will later fit the ecliptic (solar and planetary plane). The ecliptic is fixed in the correct position by four metal pins which are fitted in the inner edge of the celestial sphere. For this you need to cut narrow slits into the two inner layers with a sharp knife. Since the ecliptic is tilted by 23.4º against the horizon, these slits are in different places on each arc.

Step 41: Glue the large inner part 1 and the small inner part 4 [J1 and J4, sheet 11] together on their designated glue marks with their front sides facing each other. The edges, especially the ends have to be exactly flush. Now glue the large inner part 3 [J3, sheet 11] onto the other half of part 1, making sure that it abuts part 4 without a gap. Finally glue inner part 2 [J2, sheet 11] onto the free end of part 3. As always make sure all edges are flush.

This concludes the construction of the inner part of arc 1.



Step 42: Cut out the narrow slit depicted on the inner part, using a sharp knife. The slit is 1.3 mm wide and reaches to the centre of the ring. Use one of the metal pins to check the width: the pin should be a tight fit in the slit.
HINT: Although the slit is depicted on both sides, it is possible that the position differs slightly. Nevertheless, this small difference does not affect the function.

Step 43: Glue the outer parts 1 and 2 [J5 and J6, sheet 9] onto their designated glue marks. As usual, make sure that all edges are completely flush. The slit will be exactly under the 0º mark. One end of the arc is now marked "N", the other "S".

Step 44: In the same manner glue the other outer parts 3 and 4 [J7 and J8, sheet 9] onto the other side of the arc. The "N" and "S" markings must match on both ends. The slit has now become a 1.3 x 1.3 mm hole. Push one of the metal pins into the hole and check that it goes in about halfway. Then glue it into this position.
The first arc is now complete. On both sides you will find on the northern half the markings for +66.6º and +23.4º, and on the southern half -66.6º and -23.4º. (Due to a printing error, a small number of copies have "65.5" printed on them instead of "66.6'. In that case you should correct the error using a fine black pen)

Tip: *If you lose one of the pins, you can easily make a new one from a paperclip or a piece of thin wire.*

Chapter K

The Celestial Sphere, Arc 2

The second arc of the celestial sphere is constructed in the same manner as the first one. The only difference is the position of the slit: on the second arc it lies under the +23.4º mark. The numbering of the parts is identical, only the "J" is replaced by a "K", therefore the instructions are rather compact.

Step 45: Glue the inner parts 1 and 4 [K1 and K4, sheet 11] with their front sides flush together. Glue part 3 [K3, sheet 11] onto the other half of part 1, onto which you glue part 2 [K2, sheet 11]. Cut out the slit as before.

Step 46: Glue the outer parts 1 and 2 [K5 and K6, sheet 9] onto the inner arc, the slit has to lie under the +23.4º mark. Then glue the outer parts 3 and 4 [K7 and K8, sheet 9] onto the other side of the arc. The "N" and "S" markings must match on both ends. Glue the metal pin into the hole at +23.4º.

Chapter L

The Celestial Sphere, Arc 3

The third arc of the celestial sphere is identical to the first one. The hole is in the 0º position as well.

Step 47: Glue the inner parts 1 and 4 [L1 and L4, sheet 12] with their front sides flush together. Glue part 3 [L3, sheet 12] onto the other half of part 1, onto which you glue part 2 [L2, sheet 12]. Cut out the slit.

Step 48: Glue the outer parts 1 and 2 [L5 and L6, sheet 10] onto the inner arc, the slit is under the 0º mark. Then glue the outer parts 3 and 4 [L7 and L8, sheet 10] onto the other side of the arc. The "N" and "S" markings must match on both ends. Glue the metal pin into the hole at 0º.

First glue the north/south support in place and make sure that its inner edge is flush with the inner edge of the cutouts, otherwise the meridian ring would not fit inside. It is possible that you have to pull the arms slightly apart to accomplish this. Afterwards glue the brackets of the east/west support in place.
That concludes the construction of the horizon frame. Put it back on its feet, slide the meridian in its position and check that it can rotate inside without too much friction.

Chapter z-G:

The Connection Brackets (collapsible version)

The connection between the four arms of the support and the horizon ring consists of eight connection brackets, two for each arm. The brackets are first screwed to the support and afterwards glued to the horizon ring. Similar to the feet, the part of the brackets that is screwed to the support is reinforced by an additional layer of cardboard. The brackets are numbered, but are actually identical and can therefore be used in any order.

Step 30: Fold the brackets 1 to 8 forwards along the perforation [z-G1 to z-G4, sheet 13 + z-G5 to z-G8, sheet 14].

Step 31: Cut off the indicated half of the reinforcement brackets 9 to 16 along the perforation [z-G9 to z-G12, sheet 15 + z-G13 to z-G16, sheet 16]. Glue each remaining half of a bracket flush behind one of the brackets 1 to 8, taking care that the holes are completely flush. These reinforced halves will be screwed to the ends of the support in the next step.

Step 32: Put the support upside down on your work surface, so that the base is on top and the arms stand flat on the worktop. Screw two brackets with their reinforced parts on each side of every arm, so that their other part lies flat on the work surface.

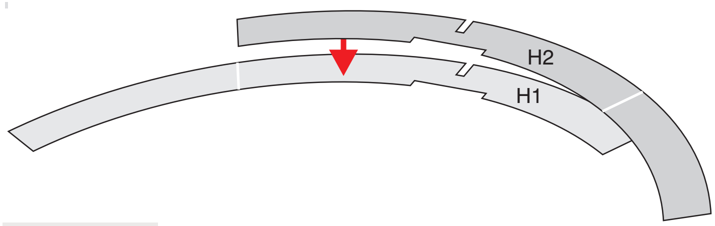
Step 33: Put the horizon ring with the degree scale downwards onto your work surface and stand the support upside down on top if it. The connection brackets are then standing on their respective glue marks on the underside of the horizon. Check that the north/south support (the one with the continuous semicircular inner edge) is standing on the parts of the horizon that have the cutouts for the meridian. First glue the north/south support in place, but take care that the edges of the support don't receive any glue. Make sure that the inner edge of the support is flush with the inner edge of the cutouts, otherwise the meridian ring would not fit inside. It is possible that you have to pull the arms slightly apart to accomplish this. Afterwards glue the brackets of the east/west support in place.
That concludes the construction of the horizon frame. Put it back on its feet, slide the meridian in its position and check that it can rotate inside without too much friction.

Chapter H

The Equinoctial

The equinoctial will be mounted inside the meridian ring, turned by 90º. It is used to show apparent local time, which reads 12 o'clock when the Sun is exactly south from the observer. The equinoctial is also constructed from four layers of cardboard, consisting of four parts each. It will be connected to the meridian by two cross-shaped brackets.

Step 34: Glue the equinoctial inner parts 1 and 2 [H1, sheet 5 + H2, sheet 6] together on their designated glue marks with their front sides facing each other, as depicted. The slot on the outer edge (to slide the meridian in), the shallow rectangular cutout on the inner edge (for the bracket), and all edges must be completely flush. The parts protrude by about a third on each side.



Step 35: Glue the inner part 3 [H3, sheet 5] onto the protruding part of part 2 [H2]. Then carry on with part 4 [H4, sheet 6] and parts 5 to 8 [H5 and H7, sheet 7 + H6 and H8, sheet 8]. With the last part the inner two layers form a complete ring.

Step 36: Glue the upper equinoctial parts 1 to 4 [H9 and H10, sheet 1 + H11 and H12, sheet 2] onto their designated glue marks on one side of the equinoctial.

Important: *On the "upper" side of the equinoctial the hours are counted clockwise from 0 to 24, on the "lower" side they are counted anti-clockwise. Make sure that the four segments are glued on in the correct order.*

Step 37: Glue the lower equinoctial parts 1 to 4 onto the other side of the equinoctial [H13 and H14, sheet 3 + H15 and H16, sheet 4].

Important: *The hour marks on the upper and lower side should lie exactly on top of each other. Make sure that the ring doesn't warp while the glue sets.*

Step 38: Take the meridian ring out of the frame and slide the equinoctial with its outer slots into the inner slots of the meridian ring so that the rings are at right angles. You need to be quite careful when doing this: the equinoctial must be bent slightly before the slots fully engage and the inner edges of the rings are flush. Put the meridian ring back into the horizon frame.

Important: *The side of the equinoctial that shows the hours in a clockwise direction has to point northwards, to the semicircle of the meridian that shows positive degrees.*

To make sure the equinoctial stays at right angles and doesn't wobble, the connection with the meridian ring is reinforced with brackets.

Chapter M

The Celestial Sphere, Arc 4

The fourth arc of the celestial sphere is identical to the second one. Only the hole is in the -23.4º position, not at +23.4º.

Step 49: Glue the inner parts 1 and 4 [M1 and M4, sheet 12] with their front sides flush together. Glue part 3 [M3, sheet 12] onto the other half of part 1, onto which you glue part 2 [M2, sheet 12]. Cut out the slit.

Step 50: Glue the outer parts 1 and 2 [M5 and M6, sheet 10] onto the inner arc, the slit is under the -23.4º mark. Then glue the outer parts 3 and 4 [M7 and M8, sheet 10] onto the other side of the arc. The “N” and “S” markings must match on both ends. Glue the metal pin into the hole at -23.4º.

Chapter v-N

Celestial Sphere, Northern Bearing (glued version)

To enable the celestial sphere to turn, we need bearings on both ends of its axis. These bearings are also used to turn the four semicircular arcs of the celestial sphere into two perpendicular interconnected rings. Each bearing consists of four brackets with two 1.3 mm wide slots. These slots are at the bottom of two of the brackets and on the top of the other two, so that the brackets can be pushed into each other to form a double cross. Each bracket is made up from two layers of cardboard. There are again two different varieties: one for the glued version (without holes) and one for the collapsible version (with holes).

Step 51: Glue the bracket parts 1 and 2 of the northern bearing [v-N1, sheet 1 + v-N2, sheet 5] back to back, making sure they are completely flush. In the same way glue together the the bracket parts 3 and 4 [v-N3, sheet 2 + v-N4, sheet 6], as well as bracket parts 5 and 6 [v-N5, sheet 1 + v-N6, sheet 5], and bracket parts 7 and 8 [v-N7, sheet 2 + v-N8, sheet 6].

Step 52: First without glue, fit the two brackets with the slots in their lower sides into the slots of the two other brackets, forming a double cross. On the upper edge of this double cross is a shallow recess of about 0.5mm that will receive a PVC bearing disc. For this take one of the PVC disks and cut off four sides to form a square with 5mm long edges. Check that this square fits into the recess, with its hole exactly in the centre of the hole formed by the four crossed brackets.

Step 53: The quadratic channel in the centre of the bracket will later receive the axle of the celestial sphere. Push one of the wooden sticks through the hole. The bearing should revolve quite easily around the stick. If the friction is too large, take the bearing apart, put the brackets facedown onto the work surface and indent them slightly in the middle, using the wooden stick or the back of a knife. This widens the hole slightly. Now glue the northern bearing together and glue the PVC disk into its recess (with super glue, if available). Make sure that no glue enters the hole.

Chapter z-N

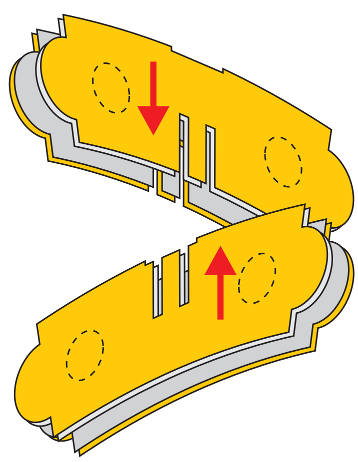
Celestial Sphere, Northern Bearing (collapsible version)

To enable the celestial sphere to turn, we need bearings on both ends of its axis. These bearings are also used to turn the four semicircular arcs of the celestial sphere into two perpendicular interconnected rings. Each bearing consists of four brackets with two 1.3 mm wide slots. These slots are at the bottom of two of the brackets and on the top of the other two, so that the brackets can be pushed into each other to form a double cross. Each bracket is made up from two layers of cardboard. There are again two different varieties: one for the glued version (without holes) and one for the collapsible version (with holes).

Step 51: Glue the bracket parts 1 and 2 of the northern bearing [z-N1, sheet 9 + z-N2, sheet 11] back to back, making sure they are completely flush. In the same way glue together the the bracket parts 3 and 4 [z-N3, sheet 9 + z-N4, sheet 11], as well as bracket parts 5 and 6 [z-N5, sheet 9 + z-N6, sheet 11], and bracket parts 7 and 8 [z-N7, sheet 9 + z-N8, sheet 11].

Step 52: First without glue, fit the two brackets with the slots in their lower sides into the slots of the two other brackets, forming a double cross. On the upper edge of this double cross is a shallow recess of about 0.5mm that will receive a PVC bearing disc. For this take one of the PVC disks and cut off four sides to form a square with 5mm long edges. Check that this square fits into the recess, with its hole exactly in the centre of the hole formed by the four crossed brackets.

Step 53: The quadratic channel in the centre of the bracket will later receive the axle of the celestial sphere. Push one of the wooden sticks through the hole. The bearing should revolve quite easily around the stick. If the friction is too large, take the bearing apart, put the brackets facedown onto the work surface and indent the them slightly in the middle, using the wooden stick or the back of a knife. This widens the hole slightly. Now glue the northern bearing together and glue the PVC disk into its recess (with super glue, if available). Make sure that no glue enters the hole.



Chapter v-O

Celestial Sphere, Southern Bearing (glued version)

The southern bearing of the celestial sphere is, apart from the label, identical to the northern one. Its construction is the same.

Step 54: Glue the bracket parts 1 and 2 [v-O1, sheet 3 + v-O2, sheet 7] back to back. Do the same with the bracket parts 3 and 4 [v-O3, sheet 4 + v-O4, sheet 8], 5 and 6 [v-O5, sheet 3 + v-O6, sheet 7], as well as 7 and 8 [v-O7, sheet 4 + v-O8, sheet 8]. Glue the brackets together and fit the PVC disk.

Chapter z-O

Celestial Sphere, Southern Bearing (collapsible version)

The southern bearing of the celestial sphere is, apart from the label, identical to the northern one. Its construction is the same.

Step 54: Glue the bracket parts 1 and 2 [z-O1, sheet 10 + z-O2, sheet 12] back to back. Do the same with the bracket parts 3 and 4 [z-O3, sheet 10 + z-O4, sheet 12], 5 and 6 [z-O5, sheet 10 + z-O6, sheet 12], as well as 7 and 8 [z-O7, sheet 10 + z-O8, sheet 12]. Glue the brackets together and fit the PVC disk.

Chapter P

The Ecliptic (Solar Orbit)

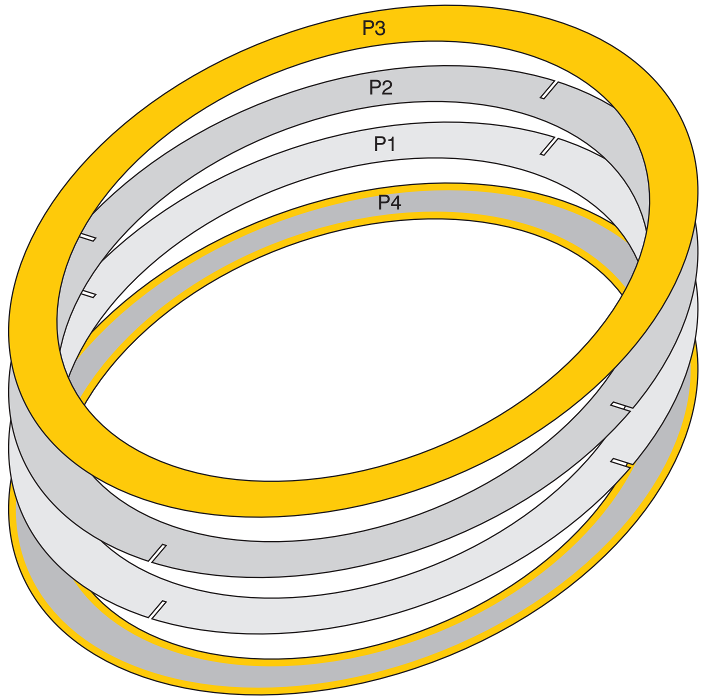
The ecliptic consists of four layers of cardboard, this time complete rings. To be able to fit the metal pins of the celestial sphere, you need to cut slits into the outer edges of the two inner layers.

Step 55: Glue the two inner parts 1 and 2 of the ecliptic [P1, sheet 11 + P2, sheet 12] back to back and cut out the four slits for the metal pins.

Important: *It is possible that the markings for the slits on the two sides are slightly shifted against each other after glueing the parts together. Therefore it is best to cut all slits from one side of the inner layers, without turning them over.*

On the outer parts 1 and 2 of the ecliptic [P3, sheet 9 + P4, sheet 10] are three scales: the outer one shows the constellations which the ecliptic passes through, the middle one shows all days in the year, and the inner one has a degree scale, showing the ecliptic longitude and the signs of the zodiac.

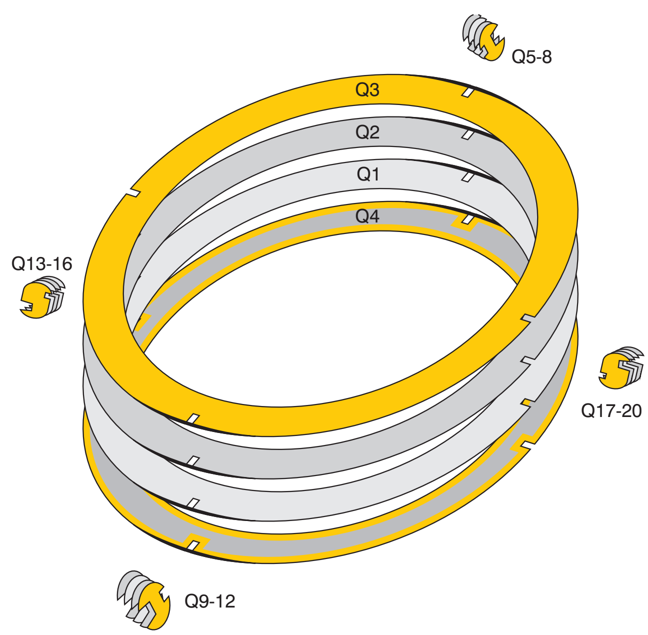
Step 56: First glue the outer part 1 [P3, sheet 9] onto the inner part of the ecliptic. The markings for 0º/360º, 90º, 180º, and 270º have to coincide with the slits for the metal pins. Then glue the outer part 2 [P4, sheet 10] onto the other side of the inner part. Take care that the degree markings on both sides coincide exactly (90º opposite 90º, 180º opposite 180º, etc).
The ecliptic is now finished. Before fitting it to the celestial sphere, we first need to construct the lunar orbit and fit it to the ecliptic.



Chapter Q

The Lunar Orbit

The lunar orbit is tilted against the ecliptic by 5.2º and therefore they intersect at two points, the so-called "lunar nodes". Since the lunar nodes move around the ecliptic once every 18.6 years, we need to mount the lunar orbit inside the ecliptic in a moveable way. This is accomplished by two holders for the lunar nodes at the intersects and two for the orbit that define the angle. At the position of the node holders the orbit ring has to be cut slightly narrower so it doesn't rub against the ecliptic. The lunar orbit is again glued together from four layers of cardboard.



Step 57: With a pair of sharp scissors, cut off a narrow strip from the lunar orbit inner part 1 [Q1, sheet 11] at the two places denoted by black print. The ring, which is normally 14mm wide, is then only 13mm wide at these. The cut should be very gradual, so that you hardly notice the transition. *HINT: the three other parts of the lunar orbit need to be cut as well, but only after they are glued in*

place. That ensures that all cuts are equal and parallel, and the edge is smooth and even.

Step 58: Glue the uncut inner part 2 [Q2, sheet 12] back to back onto part 1 [Q1]. The slits for the holders have to lie exactly on top of each other. Afterwards cut off the slivers where part 1 has already been narrowed in the last step. The scissor blade will glide along the cut on part 1, which ensures that the new cut will be exactly parallel to the first one.

Step 59: Glue outer part 1 [Q3, sheet 9] onto one side of the inner part. The parts marked “ascending node” and “descending node” have to lie over the trimmed-off parts. Now trim the edge of the new layer as well, as described in the last step.

Step 60: Glue outer part 2 [Q4, sheet 10] onto the other side, so that its ascending and descending nodes are opposite of the ascending and descending nodes of outer part 1. When the glue has set, trim down the edge again, if necessary you can sand down any irregularities.

The lunar orbit is also divided into three concentric bands: The outer one shows 27 round symbols with directional arrows, which show the distances the Moon covers in 24 hours, in the middle band, close to the nodes, you find the areas where solar or lunar eclipses can happen (P: partial, T: total), and in the inner band you find the marks for ascending and descending lunar nodes.

Step 61: Glue the lunar node holder parts 2 and 3 [Q6 and Q7, sheet 15] on top of each other and then the parts 1 and 4 [Q5 and Q8, sheet 13] on both sides. In the same manner glue lunar node holder parts 5 to 8 [Q9 to Q12, sheet 14 and 16] on top of each other. Let dry thoroughly.

Step 62: First without glue push the node holders into their slots in the lunar orbit (where it has been trimmed off). They have to be pushed in as far as possible. If necessary you can widen the slots a bit. Now glue the lunar node holders into this position.

Step 63: Glue the lunar orbit holders 1 to 4 [Q13 to Q16, sheet 13 and 15] on top of each other. Do the same with the lunar orbit holders 5 to 8 [Q17 to Q20, sheet 14 and 16]. Put the lunar orbit in front of you, so that the arrows between the Moon symbols point counterclockwise and the lunar node symbol “aufsteigender Knoten ascending node” is on top. The two empty slots are then on the left and right of the orbit ring. Push one of the lunar orbit holders into the left slot, so that its side with the wedge-shaped slot points downwards. Push the other one into the right hand slot, but this time so that its wedge-shaped slot points upwards. If necessary you can widen the slots for the holders a bit. Now glue the lunar orbit holders into their position and let dry well.

Step 64: Fit the lunar orbit into the ecliptic. The cardboard rings have to be carefully bent for this, until the inner edge of the ecliptic snaps into the wedge-shaped slots of the holders.

Important: *Make sure that you fit the lunar orbit the right way round: The arrows between the moon symbols have to point in the same direction as the date scale on the ecliptic. If the dates on the side in question increase in the clockwise direction, then the arrows on that side have to point clockwise as well.*

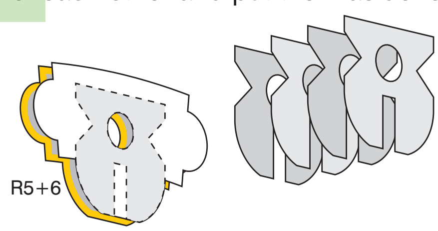
Chapter v-R

Celestial Axis, Northern Holder (glued version)

The central sphere (Earth) with the celestial axis made from wooden sticks (Chapter T) is held inside the meridian with a northern and southern holder. The holders are only partly fastened at first. After the celestial axis is fitted they are glued in permanently.

Step 65: Glue the inner holders 1 to 4 [R1 to R4, sheet 1 to 4] on top of each other to form a block. *Reminder: the holders were already removed from the sheets in Chapter F, steps 30ff.* After the glue has set, check that the block of holders fits into the northern cutout of the meridian. If necessary, trim back the block or the cutout and then glue the block of holders in place. Its surfaces must be completely flush with the meridian.

Step 66: Glue the outer holders 1 and 2 [v-R5, sheet 1 + v-R6, sheet 5] first on top of each other and then on one side of the meridian to cover the block of inner holders. **Important:** *The northern holder has to be fitted to the side of the meridian with the positive angles.*
Glue the outer holders 3 and 4 [v-R7, sheet 2 + v-R8, sheet 6] on top of each other and put them aside for later.



Chapter z-R

Celestial Axis, Northern Holder (collapsible version)

The central orb (Earth) with the celestial axis, made from wooden sticks (Chapter T), is held inside the meridian with a northern and southern holder. Each holder consists of two parts, one of which is glued to the axis and is later fitted to the meridian using the other part and a barrel bolt.

Step 65: Glue the inner holders 1 to 4 [R1 to R4, sheet 1 to 4] on top of each other to form a block. *Reminder: the holders were already removed from the sheets in Chapter F, steps 30ff.* After the glue has set, check that the block of holders fits into the northern cutout of the meridian. If necessary, trim back the block or the cutout so that it fits flush with the surface of the meridian and can be taken out without damage.

Step 66: Glue the outer holders 1 and 2 [z-R5, sheet 1 + z-R6, sheet 5] on top of each other. Then glue the block of inner holders, with the edge and hole flush, onto the designated glue mark on the inside of the outer holder. Glue the outer holders 3 and 4 [z-R7, sheet 2 + z-R8, sheet 6] on top of each other and put both parts aside for later. They will be needed when the celestial axis is fitted.

Chapter v-S

Celestial Axis, Southern Holder (glued version)

The southern holder of the celestial axis is identical to the northern one, so the steps are only described briefly.

Step 67: Glue the inner holders 1 to 4 [S1 to S4, already removed in Step 30ff] on top of each other and then into the southern cutout of the meridian ring.

Step 68: Glue the outer holders 1 and 2 [v-S5, sheet 3 + v-S6, sheet 7] on top of each other and then on the meridian ring. Glue the outer holders 3 and 4 [v-S7, sheet 4 + v-S8, sheet 8] on top of each other and put them aside.

Chapter z-S

Celestial Axis, Southern Holder (collapsible version)

The southern holder of the celestial axis is identical to the northern one, so the steps are only described briefly.

Step 67: Glue the inner holders 1 to 4 [S1 to S4, already removed in Step 30] on top of each other and then check that they fit into the southern cutout of the meridian ring.

Step 68: Glue the outer holders 1 and 2 [z-S5, sheet 3 + z-S6, sheet 7] on top of each other, then glue the inner holder block onto the glue mark on their back. Glue the outer holders 3 and 4 [z-S7, sheet 4 + z-S8, sheet 8] on top of each other and put all aside.

Chapter T

The Celestial Axis

The celestial axis is fitted between the north and south pole of the meridian and carries a wooden sphere in the middle, that is glued together from two halves. Its centre is at the centre of the Planetarium. The sphere can be painted as a globe, or just plain-coloured (e.g. golden) if you want it to just symbolise the position of the observer in the centre of the celestial sphere.

Tip: *If you want to draw the latitude and longitude grid onto the central sphere, carry on with the next step. If you want to paint the sphere, for example blue with white clouds or just golden, skip the next two steps and carry on with Step 71.*

Step 69 (optional): First paint the two halves of the sphere with the colour of your choice. The latitude and longitude grid is easier to draw before the two halves are joined. Cut out the latitude template at the end of the instructions and reinforce it with a layer of thin cardboard. Cut out the template for the longitude and temporarily attach it to the flat surface of one hemisphere, for example with blu tack. Using a fine pencil, extend the lines onto the wood, so that they are visible on the edge of the hemisphere. Remove the template again, place the hemisphere onto your work surface, and draw straight lines from the hole to each of the pencil marks. For this you can use the semicircular cutout of the latitude template. Repeat this step with the other hemisphere. This results in 24 lines of longitude with 15º distance.

Step 70: Stand the latitude template on one of the hemispheres and make 5 pencil marks on each line of longitude. Then connect the marks to complete the lines of latitude. When you hold the hemispheres together you will see a sphere with 24 lines of longitude and 24 lines of latitude, with distances of 15º each. With the help of a standard depiction of the Earth's globe it is relatively easy to now copy the outlines of the continents onto the sphere.

Step 71: Choose the two straightest wooden sticks for the axis, the third one is a reserve. Check that the blunt ends of the sticks fit tightly into the holes of the hemispheres. If necessary you can thin the ends slightly with sandpaper. Push one stick into the the hole on the round side of one hemisphere and stand it on your work surface. By turning the hemisphere, check that the wooden stick is perpendicular to the work surface and glue it into this position. Repeat this procedure with the other wooden stick and the other hemisphere and then glue the two hemispheres together to form the globe with the celestial axis going through its centre.

Step 72 (glued version): Shorten both ends of the axis to 110mm length and check that it can be easily fitted to the holders in the meridian. Turn the meridian in the horizon frame until one of the holders is on top (zenith) and the other one at the bottom (nadir) and put the axis into the holders. If the axis is too long, carefully cut off the same amount on both ends. Don't glue in the axis just yet.

Step 72 (collapsible version): Push the northern axis holder with the glued-on block of holders into the northern cutout of the meridian, so that the outer holder abuts the meridian and the inner block is flush with the other side. *Remember: the northern cutout is in the half of the meridian that has the positive degree markings.* In the same way insert the southern axis holder into its cutout in the meridian. Now check if the axis fits into the two holders. If it is too long, carefully cut off the same amount on both ends. Don't glue in the axis just yet.

Step 73: Now paint the celestial axis, e.g. golden, as well as the central sphere, in case you haven't already painted it.
All elements of the Desktop Planetarium are finished. We now show you how to put them all together and fit the celestial sphere, again separated into the glued and collapsible versions.

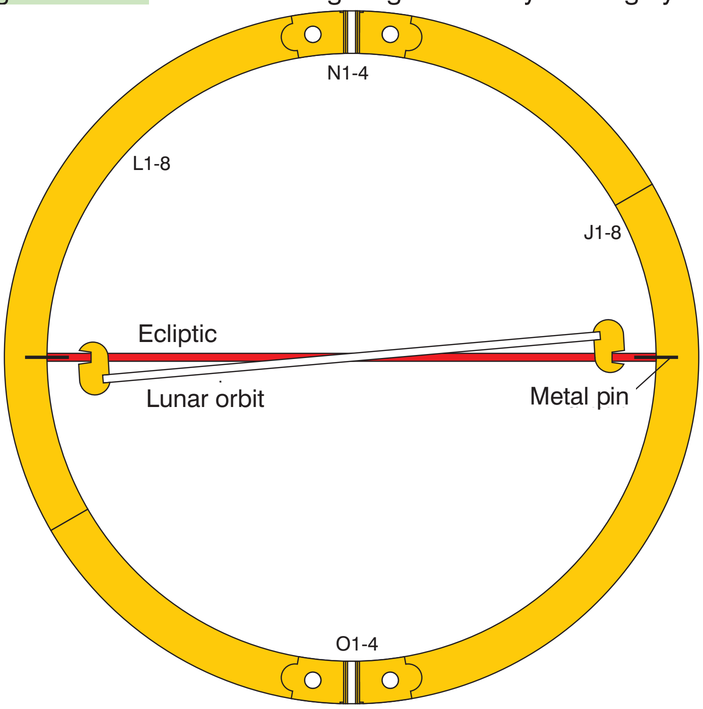
Chapter v-U

Assembly of the Celestial Axis (glued version)

To make up the celestial sphere, its four semicircular arcs are connected by the northern and southern bearing to form two complete interconnected rings at right angles. At the same time the ecliptic with the lunar orbit is fitted to the metal pins sticking out from the arcs.

Step 74: For this step you will need 4 clothes-pegs, the 4 semicircles of the celestial sphere, the northern and southern bearings, as well as the ecliptic with the mounted lunar orbit. Take one of the arcs that have the metal pin at the 0º mark and push its "N"-end into one of the slits of the northern bearing. Push it in as far as possible and adjust its angle so its rounded side is parallel to the rounding of the bearing. Use a clothes-peg to secure it in place temporarily. In the same way stick the other end of the arc into one of the slits of the southern bearing and secure it with another clothes-peg.

Step 75: Take the other arc with the metal pin at the 0º mark, fit it onto the bearing slits opposite the ones used by the first arc, and secure it with clothes-pegs. You now have a complete ring. Check again that the positive degree markings are on the northern half of the ring and the the negative numbers on the southern one. Now glue one of the arcs into the bearings by removing it, applying some glue to the slits and inserting it again. Let dry thoroughly.



Step 76: Put the ecliptic in front of you so that the degree markings increase in the counterclockwise direction. The names of the months are ascending in the same direction and the arrows on the lunar orbit point counterclockwise as well. This side of the ecliptic has to point towards the northern bearing of the celestial sphere. *Reminder: The holes in the ecliptic for the metal pins are in the positions 0º/360º (21st March), 90º (21st June), 180º (23rd September), and 270º (22nd December).* Now remove one of the clothes-pegs, insert the ecliptic into the celestial ring, and stick the metal pins into the holes at 0º (21st March) and 180º (23rd September). Check again that the ecliptic points north with its counterclockwise markings, and then glue the second arc into the northern and southern bearing as well.

Step 77: Take the arc that has the metal pin at +23.4º, find the hole at 90º (21st June) on the ecliptic, and stick the metal pin into this hole while at the same time sticking the ends of the arc into the northern and southern bearings. Glue the arc into this position. The ecliptic is now tilted inside the celestial sphere: it has an angle of 23.4º against the celestial equator (which you have to imagine passing through the 0º markings of the arcs, as the celestial equator hasn't got a ring of its own).

Step 78: Finally glue the last arc into the bearings of the celestial sphere. This one has the metal pin at -23.4º, which is received by the last hole in the ecliptic at 270º (22nd December).

This concludes the construction of the celestial sphere. It only remains to mount it inside the meridian ring.

Chapter z-U

Assembly of the Celestial Axis (collapsible version)

To make up the celestial sphere, its four semicircular arcs are connected by the northern and southern bearing to form two complete interconnected rings at right angles. At the same time the ecliptic with the lunar orbit is fitted to the metal pins sticking out from the arcs.

Step 74: For this step you will need the 4 semicircles of the celestial sphere, the northern and southern bearings, 8 barrel bolts, as well as the ecliptic with the mounted lunar orbit. Take one of the two arcs that have the metal pin at the 0º mark and push its "N"-end into one of the slits of the northern bearing. Push it in as far as possible and check that the holes in the arc and the bearing are exactly flush. If necessary you can trim off the end of the arc by cutting or filing. Secure the arc in the bearing with a barrel bolt. In the same way fit the other end of the arc in the southern bearing with another barrel bolt.

Step 75: Take the other arc with the metal pin at the 0º mark, fit it onto the bearing slits opposite the ones used by the first arc. You now have a complete ring. Check again that the positive degree markings are on the northern half of the ring and the the negative numbers on the southern one. Secure the arc with one barrel bolt, but don't tighten it completely yet.

Step 76: Put the ecliptic in front of you so that the degree markings increase in the counterclockwise direction. The names of the months are ascending in the same direction and the arrows on the lunar orbit point counterclockwise as well. This side of the ecliptic has to point towards the northern bearing of the celestial sphere. *Reminder: The holes in the ecliptic for the metal pins are in the positions 0º/360º (21st March), 90º (21st June), 180º (23rd September), and 270º (22nd December).* Now insert the ecliptic into the celestial ring and stick the metal pins into the holes at 0º (21st March) and 180º (23rd September). Check again that the ecliptic points north with its counterclockwise markings and secure the second arc with barrel bolts in both bearings.

Step 77: Take the arc that has the metal pin at +23.4º, find the hole at 90º (21st June) on the ecliptic, and stick the metal pin into this hole while at the same time sticking the ends of the arc into the northern and southern bearings. Screw it into this position. The ecliptic is now tilted inside the celestial sphere: It has an angle of 23.4º against the celestial equator (which you have to imagine passing through the 0º markings of the arcs, as the celestial equator hasn't got a ring of its own).

Step 78: Finally screw the last arc into the bearings of the celestial sphere. This has the metal pin at -23.4º, which is received by the last hole in the ecliptic at 270º (22nd December).

This concludes the construction of the celestial sphere. It only remains to mount it inside the meridian ring.

Chapter v-W

Fitting the Celestial Sphere into the Meridian (glued version)

The celestial sphere is fitted inside the meridian ring with the help of the celestial axis.

Step 79: Push the celestial axis from the inside first through one, then through the other quadratic channel in the northern and southern bearing, so that it sticks out equally at both ends. Check that the celestial sphere rotates easily about the axis. If there is too much friction, mark the parts of the axis that go through the bearings and reduce the diameter in these areas with sandpaper or a knife until it turns easily. You might have to reapply the paintwork at the ends afterwards.

When fitting the celestial sphere into the meridian, you have to fit the equinoctial at the same time. This demands a little bit of skill, but is actually not hard:

Step 80: Take the meridian ring from the horizon frame and hold it upright with the "N"-mark on top. Hold the equinoctial horizontally, with the side on top that shows the hours in a clockwise direction. Push the equinoctial only partly into its slots, so that the celestial sphere can be put into the middle of the meridian and equinoctial, like an apple into a basket. Now push the equinoctial fully into the meridian ring, so that it snaps into its position and the brackets can be pushed home.

Step 81: Lay the meridian flat onto the horizon, so that the open sides of the axle holders are facing upwards. Push the ends of the axis into the slots of the axle holders, apply some glue to the ends of the axis and glue the remaining two outer axle holders on top, "N" on "N" and "S" on "S".

Chapter z-W

Fitting the Celestial Sphere into the Meridian (collapsible version)

The celestial sphere is fitted inside the meridian ring with the help of the celestial axis.

Step 79: Push the celestial axis from the inside first through one, then through the other quadratic channel in the northern and southern bearing, so that it sticks out equally at both ends. Check that the celestial sphere rotates easily about the axis. If there is too much friction, mark the parts of the axis that go through the bearings and reduce the diameter in these areas with sandpaper or a knife until it turns easily. You might have to reapply the paintwork at the ends afterwards.

When fitting the celestial sphere into the meridian, you have to fit the equinoctial at the same time. This demands a little bit of skill, but is actually not hard:

Step 80: Take the meridian ring from the horizon frame and hold it upright with the "N"-mark on top. Hold the equinoctial horizontally, with the side on top that shows the hours in a clockwise direction. Push the equinoctial only partly into its slots, so that the celestial sphere can be put into the middle of the meridian and equinoctial, like an apple into a basket. Now push the equinoctial fully into the meridian ring, so that it snaps into its position and the brackets can be pushed home.

Step 81: Push the two axle holders with the glued-on inner holders into the cutouts in the meridian ring. Now lay the meridian flat onto the horizon, so that the open sides of the axle holders are facing upwards. Push the ends of the axis into the slots of the axle holders, and glue the axis into their slots (but not the axle holders into the meridian ring). Let the glue dry thoroughly.

Hint: *If you have painted the central sphere as a globe, we would recommend that you turn it so that your home location points towards the meridian and the "12"-mark of the equinoctial.*

After the glue has set, fit the last two outer axle holders with barrel bolts, "N" on "N" and "S" on "S".

Finally put the meridian with the fitted celestial sphere back into the horizon frame. The mechanical parts of your Desktop Planetarium are now finished.

Chapter X

The Planets, the Moon, and the Sun

The Planets, Moon, and Sun consist of foam rubber. You can deform them with pressure and also push them back into the correct shape. They are pushed onto the outside of the ecliptic with their slot. The Moon is pushed onto the inside edge of the lunar orbit.

Step 82: The two large balls represent Moon and Sun, the smaller balls are Mercury, Venus, Mars, Jupiter, and Saturn. They can easily be coloured with felt tip pens, preferably ones with light-resistant pigments. Traditionally Mercury is painted yellow, Venus green, Mars red, Jupiter orange, and Saturn dark blue. The Sun can be painted golden or red, matching the colour of the ecliptic scales. In that case you should choose a darker shade of red for Mars and a lighter one for the Sun. The Moon can be painted silver or, matching the lunar orbit, white. You should bear in mind though, that because of the porous surface of the rubber balls, the colours silver and gold will not shine but stay matt.

You might want to order a second set of planets, for example to put one Sun in a summer position and one in a winter position to be able to show the difference of day lengths with just one turn of the celestial sphere. Additional planets can be stuck on the arcs of the celestial sphere to represent fixed stars.

Hint: *If you don't want to use all planets at the same time, for example if you want to concentrate on the movement of Sun and Moon, you can park the unused ones on the inside of the east/west support.*

Congratulations, your Desktop Planetarium is now complete! You have built a high quality astronomical instrument, that not only looks spectacular, but that also helps to explain and demonstrate accurately all important celestial movements.

How to set up your Desktop Planetarium:

Setting up the latitude of a location

The latitude of an observer can be read at the zenith, the highest point of the meridian. On the opposite side, at the nadir, you'll find the same value, but with the opposite sign. Example: Adjust the meridian so that the celestial axis is vertical with the "N"-mark on top, the equinoctial horizontal and parallel to the horizon, and the 12 o'clock mark at the southern point of the horizon. Now the celestial north pole is at the zenith and the celestial south pole is at the nadir. This is the setting for 90º latitude, the Earth's north pole.
For all other locations further south, the celestial north pole has to be pushed towards the north point of the horizon by turning the meridian. When the celestial north pole has reached the north point of the horizon, the celestial south pole has also reached the south point of the horizon. Now the Planetarium is set for 0º latitude, all locations on the Earth's equator. By pushing the meridian even further, you can adjust the Planetarium for all locations on the southern hemisphere of the Earth. The celestial south pole then rises above the south point of the horizon, approaching the zenith. When it reaches the zenith, the Planetarium is set for -90º latitude, the Earth's south pole.

Further examples for latitudes

North pole	+90.0º	Jerusalem	+30.8º
Arctic circle	+66.6º	Cairo	+30.0º
John O'Groats	+58.6º	Tropic of Cancer	+23.4º
Edinburgh	+56.0º	Mexico City	+19.4º
Moscow	+55.8º	Bangkok	+13.7º
London	+51.5º	Singapore	+1.3º
Land's End	+50.1º	Tropic of Capricorn	- 23.4º
Paris	+48.8º	Cape Town	-33.9º
Toronto	+43.7º	Buenos Aires	-34.6º
New York	+40.8º	Melbourne	-37.8º
Madrid	+40.1	Antarctic Circle	-66.6º

Setting the Planetarium for a certain date

The date is adjusted by moving the Sun along the middle scale of the ecliptic that shows 365 circles (one for each day of the year). The names on the outer scale show the range of the constellation through which the Sun is currently moving, the signs of the zodiac are shown on the inner scale. The degree values between the signs of the zodiac show the ecliptic longitude of the Sun.
Constellations are actually random groups of fixed stars in the night sky that have been given their names by astronomers in the past. They should not be confused with the signs of the zodiac, which are 30º long arcs on the ecliptic and which take their names from the astronomical constellations. They are only used in *Astrology,* and because orbits have shifted over the centuries, they don't match with the constellations anymore.

Turning the celestial sphere

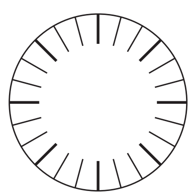
Always turn the celestial sphere so that the Sun rises in the east and sets in the west. This way it moves along the hours on the equinoctial in ascending order. This is correct for all positions of the celestial poles, even when the celestial south pole is above the horizon: for locations in the southern hemisphere the Sun at noon is in the north, and therefore moves from right to left, which feels confusing for European observers. A full rotation of the celestial sphere takes slightly less than a day. Since our clock is determined by the Sun and not the stars, and the Sun moves a short distance along the ecliptic every day, a solar day is 4 minutes longer than a sidereal day: 24 hours. Because of the daily rotation of the celestial sphere, everything moves from east to west ("left to right"). In addition we have the slower movements of Sun, Moon, and planets against the background of the fixed stars. Apart from some exceptions these movements point in the opposite direction and are superimposed by the daily rotation of the celestial sphere.

Setting the Planetarium for a certain time of day

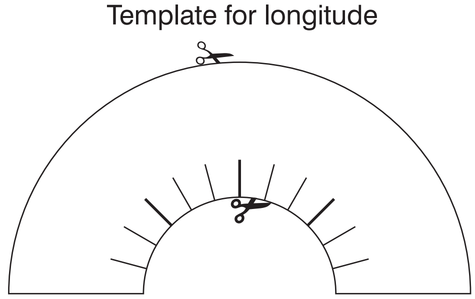
The time of day can be determined by the position of the Sun with respect to the equinoctial. When, during the rotation of the celestial sphere, the Sun reaches its highest point above the horizon, it will be directly above or below the 12 o'clock mark on the equinoctial. Keep in mind that the Planetarium shows local apparent time (like a sundial), not GMT or any other zone time. Zone times have been introduced in the 19th century and are very important for transport and economy. They can differ from the local apparent time significantly, for example in western Spain by up to 1.5 hours (during daylight saving time even an hour more!).

The position of the Moon

Clip the Moon onto the inside edge of the lunar orbit. The 27 round symbols show the distance the Moon moves in 24 hours in direction of the arrows. After 27.3 days it is back in its starting position (sidereal month), but it takes 29.5 days until it is back in the same position in regards to the Sun (lunation, synodic period), because the Sun has moved on in the mean time. Full moon means that the Moon is opposite of the Sun, when it is in front of the Sun, we have a new moon. In between the Moon is waning or waxing. The lunar nodes move once around the ecliptic every 18 years and 7 months, into the opposite direction of the Moon itself. The position of the Moon and the lunar nodes can be found in ephemeris tables for any given day of the year. You can find those on the internet, for example at www.astro.com/swisseph/swepha_e.htm. The positions in these tables are usually with regards to the ecliptic, sometimes in degree within a sign of the zodiac.



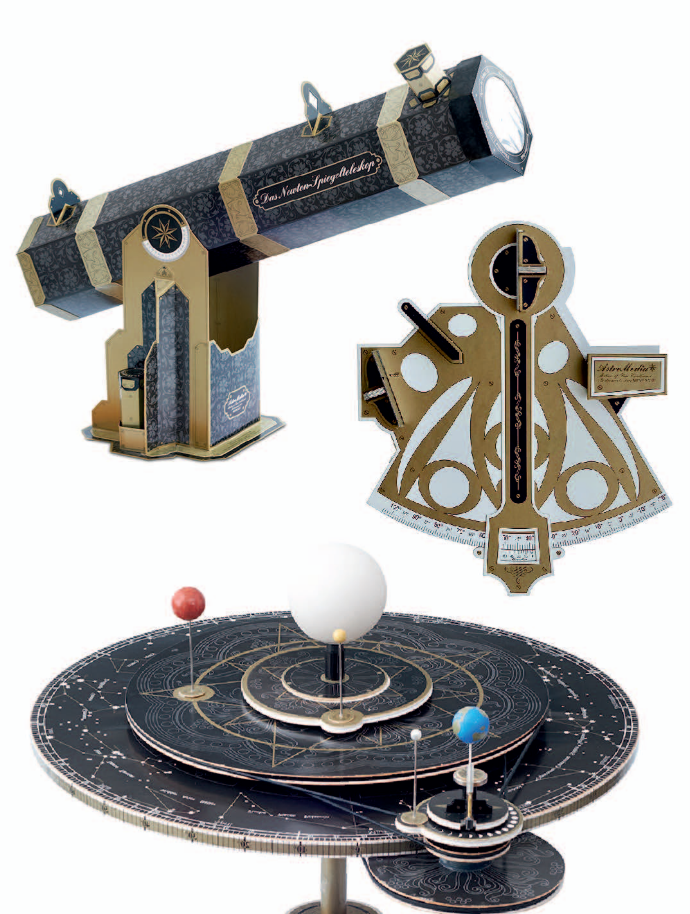
Template for longitude



Template for latitude

The position of the planets

The orbits of the two inner planets Mercury and Venus are closer to the Sun than the orbit of the Earth. Therefore they can only move a certain angular distance from the Sun when observed from the Earth: the maximal distance on the ecliptic for Venus is 47º and for Mercury only 28º. That is the reason that Mercury is so hard to observe: most of the time it is outshone by the Sun. The other three classical planets, observable with the naked eye, are Mars, Jupiter, and Saturn. They can also be in opposition to the Sun, which means that they can be on the opposite side of the ecliptic.
Keep in mind: The planets usually move in the same direction along the ecliptic as the Sun (sometimes they move in a retrograde direction). They are usually close to the ecliptic, but can also move up and down, Venus for example can reach a distance of 8º from the ecliptic. To keep things simple, this Planetarium can only show the planetary positions on the ecliptic. The actual planetary positions are also given in ephemeris tables.



Things you can demonstrate with your Desktop Planetarium

The movement of fixed stars for any place on Earth:

At the north and south pole of the Earth all stars move parallel to the horizon, they never set or rise. (Of course that is not strictly true for Sun, Moon, and planets because they move along the tilted ecliptic.) At the equator all stars move at right angles to the horizon, which explains the short periods of twilight. It also means that at the equator all stars rise and set once in every 24 hours. At any other place on Earth a certain fraction of stars are always below or above the horizon. The stars that are always above the horizon and never set are called circumpolar stars. The best known circumpolar constellation in the northern hemisphere is the Plough or Big Dipper (which is actually only a small part of the bigger constellation Ursa Major).

The origin of the seasons:

Adjust the meridian for a location in middle Europe, for example 50º, and move the Sun along the ecliptic through the whole year. For each position of the Sun revolve the celestial sphere and observe how the Sun sets and rises. If the Sun would move along the celestial equator, every day would have the same length. But since the ecliptic is tilted by 23.4º, the days are much longer during one half of the year, and much shorter during the other. Try the same for other locations on Earth (e.g north pole, polar region, tropics, equator, south pole) and compare the differences between the seasons (you will be surprised!).

Lengths of twilight:

Depending on one's needs, there are three different definitions of twilight which, in the evening, all begin with sunset. Civil twilight ends at civil dusk, when the Sun is 6º below the horizon. Nautical twilight ends at nautical dusk when the Sun is 12º below the horizon. Astronomical twilight ends when the Sun is 18º below the horizon and it is finally dark enough for all astronomical observations. The times of twilight in the morning are defined accordingly and all end when the Sun rises. There are markings on the arms of the horizon frame that help you determine in which zone of twilight the Sun is. You will be surprised if you investigate the twilight times for different latitudes and seasons: they differ significantly!

The origin of eclipses

A solar eclipse can only occur if the Moon is in front of the Sun (new moon), a lunar eclipse only if the Moon is on the opposite side of the ecliptic (full moon) and the Earth is between the Sun and the Moon. The Moon also has to be at the height of the ecliptic. Since the lunar orbit is tilted against the ecliptic by 5.2º, the last condition only occurs twice per month, when the Moon passes the lunar nodes. Therefore, new moon or full moon have to occur in the vicinity of the lunar nodes to produce an eclipse. If Sun and Moon are in the area marked “T”, the eclipse is total, in the area marked “P”, it is only partial (See also: “The position of the Moon” above).