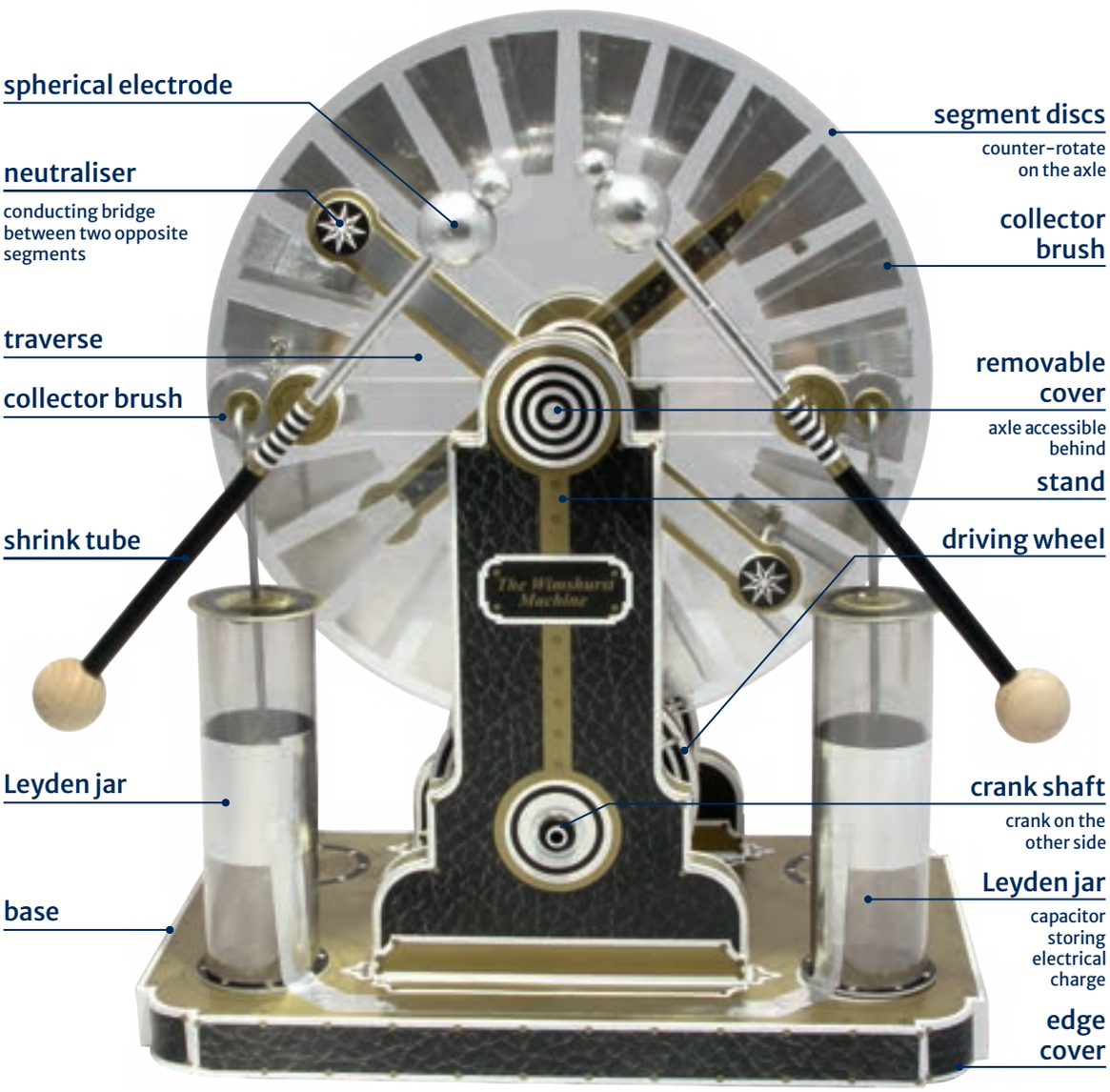
Building instructions

The Wimshurst Machine



AstroMedia

Hands-on Science Series

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The Wimshurst Machine

James Wimshurst (1832 - 1903) was an English naval engineer and inventor who worked intensely on electricity and its generation. His electrostatic generators, which he developed after 1880, were the first to offer the possibility of continuous currents at a very high voltage. These were needed for the first X-ray machines, for example.

The Wimshurst Machine is a very efficient instrument that converts mechanical energy (counter-rotating segment discs) into static electricity and stores it. The voltage is induced by separation of negative and positive charges, which is achieved by electrostatic induction. The charges are stored in Leyden jars (named after the Dutch city of Leyden) and is dissipated by sparks or arcing between the spherical electrodes.

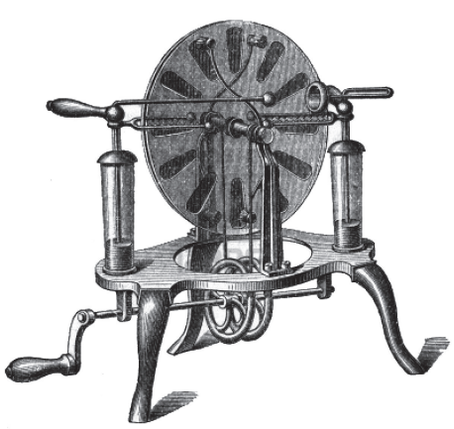
Electricity is the name for all phenomena that involve static or moving electric charges and is therefore divided into the fields of “static electricity” and “electric currents”. Some of these phenomena have been known since ancient times. The Greek philosopher Thales of Miletus discovered in 600 BC that amber can attract small particles when it is rubbed with a piece of fur. The greek word for amber is *ēlektron*, which gave this field of science its name.

Electrostatics is the scientific theory that describes the effect that substances with equal or opposite electrical charge have on each other. It shows that equal electrical charges (both positive or both negative) repel each other, opposite charges (one positive, one negative) attract each other. When electrostatic charges are equalised, for example through an electrical conductor or a spark, an electric current flows until the voltage has dropped to zero. In everyday life we frequently encounter extremely high voltages of several thousand volts, but at the same time very weak, and therefore harmless currents: the crackling of clothing made from synthetic fibres that even produces small sparks in the dark, or the light electric shock one receives sometimes when leaving a car, or when touching a door handle.

A capacitor or condenser consists of two electrically conducting surfaces that are separated by an insulator. These two surfaces are called capacitor electrodes and can store opposite electrical charges, which leads to a voltage between them. Each segment on a segment disc of the Wimshurst Machine forms a capacitor with the segment of the opposite disc facing it. Leyden jars are capacitors as well; they are capable of storing very high voltages. Originally they were made from real glass bottles with metallic coatings on the inside and outside. In this kit the Leyden jars are constructed from rolled up PVC film and aluminium foil. Without the Leyden jars, sparking discharges through the spherical electrodes would not be possible, because we could not collect a sufficient electric charge.

Electrostatic induction has the following effect: if you put a certain charge on one of the segments, an opposite charge is induced on the respective segment of the other disc. If the segments are separated by a mechanical force, which of course happens all the time when the discs are spinning, both of these charges are increased.

The neutraliser bars have collector brushes at their ends and connect each segment with the one on the opposite side of the same disc when they go past. This has the effect that the segment on one end of the bar receives the opposite charge of the segment on the other end. Then the counter-rotating discs transport the segments to the charge collectors, where the segment touching the collector always faces an equally charged segment on the other disc. Since equal charges repel each other, some of the charge is removed by the charge collectors and stored in the Leyden jars. Each disc has its own neutraliser bar pointing from top left to bottom right. The bars can be adjusted: The steeper they are, the higher the voltage and the lower the current. If you adjust them to a lower angle, the voltage goes down, but the possible current increases.



Corona discharges: Electric voltages as high as the Wimshurst Machine can produce, tend to discharge into the surrounding air from any small point and corner. These “corona discharges” can be observed in the dark. This is the reason we use spherical electrodes to discharge the Leyden jars. If the electrodes would have points, we would hardly get any electric sparks because of permanent corona discharges. High air humidity also promotes this effect and can seriously affect the function of the machine.

This kit for a Wimshurst Machine can produce voltages of up to 70,000 volts and sparks of up to 5cm length. Although the produced electricity is safe for humans, please read the safety hints at the end of these instructions.

We want to thank Dieter Hauffe for the idea and important preliminary work for this kit. This is another example of how ideas of AstroMedia customers can lead to new kits.

Contents:

- ✳ 8 pre-punched sheets of cardboard, 0.5 mm
- ✳ 2 pre-punched sheets of cardboard, 0.65 mm
- ✳ 1 pre-punched sheet of printed paper, 0.22 mm
- ✳ 1 pre-punched sheet of self-adhesive aluminium foil for segments, electrodes, and strip conductors
- ✳ 2 charge collector electrodes from bent spring steel, ø 2.5 mm
- ✳ 4 roofing nails ø 2.5 x 30 mm (neutraliser bar electrodes)
- ✳ 1 terminal connector strip, 6 pole (holder for collector brushes)
- ✳ 1 braided tinned copper wire, cross-section 0.75 mm, 150 mm length (collector brushes)
- ✳ 2 punched cork discs, ø 19.5 x 4 mm, 5 mm thick (holder for spherical electrodes)
- ✳ 5 PVC discs, ø 20 x 6 mm, 1 mm thick (bearings for drive shaft and axle)
- ✳ 2 acrylic discs ø 210 x 6 mm, 2 mm thick (segment discs)
- ✳ 1 acrylic traverse 190 x 20 mm, 4 mm thick (insulating cross beam)
- ✳ 2 pieces of aluminium tube ø 6 x 4 mm, length 83 mm and 127 mm (axle and drive shaft)
- ✳ 1 thread rod M4, length 106 mm (mounting of axle)
- ✳ 4 washers, ø 15 x 4.3 mm (mounting of axle)
- ✳ 2 nuts M4, (mounting of axle)
- ✳ 2 wooden balls, drilled through, ø 20 x 5.3 mm (spherical electrodes)
- ✳ 2 wooden balls, half drilled, ø 20 x 5.3 mm (insulated handles)
- ✳ 4 wooden balls, half drilled, ø 10 x 5.3 mm (spherical electrodes)
- ✳ 1 wooden rod, ø 5 mm, length 40 mm (crank handle)
- ✳ 2 wooden rods, ø 5 mm, length 180 mm (electrode rods)
- ✳ 2 wooden rods, ø 5 mm, length 45 mm (electrode pivots)
- ✳ 1 black shrink tube, ø 6.4 mm, length 140 mm (insulation for electrode rods)
- ✳ 2 O-rings ø 4.5 x 2.5 mm (end stops for drive shaft)
- ✳ 2 pieces of clear PVC film, 105 x 297 mm, 0.3 mm thick (Leyden jars)
- ✳ 2 rubber bands ø 100 x 3 mm (drive belts)

You will also need for assembly:

- ✳ A firm, even work surface.
- ✳ A set square or protractor to measure right angles when calibrating the calibration bench.
- ✳ Standard solvent based all purpose glue, e.g. UHU, Evo-Stik Impact, B&Q 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. Some two-component glue might be helpful to stick cardboard to the aluminium tubes (Step 68).
- ✳ Superglue - the gel variety, to glue plastic parts.
- ✳ Some sticky tape.
- ✳ A needle to glue parts with a pin marker accurately.
- ✳ A sharp knife with a fine point (thin carpet knife, craft knife, scalpel) to cut the thin holding tabs of the pre-punched parts and to remove the aluminium foil from its backing film.
- ✳ 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.
- ✳ A pair of scissors to cut the braided copper wire.
- ✳ Two small pliers to fasten the nuts of the segment discs axle. A 7 mm box spanner is helpful too.
- ✳ A small flat-headed screwdriver for the terminal strips.
- ✳ Some clothes-pegs to hold pieces in place till the glue sets.

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 S, which are broken down further into 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 15 hours for the construction (depending on experience). The more care you take, the better your Wimshurst Machine will work and look.
- ✳ Every part has its name and/or part number printed on the front or 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. E3. In the instructions part numbers are given in rectangular brackets, e.g. [E3]. Only remove the parts as you need them.
- ✳ The pre-punched aluminium parts have part numbers too. They can be recognised by the postfix “Alu” after the number. The aluminium foil itself hasn’t got numbers printed on it. Therefore you will find an image of the foil at the end of the instructions that shows the allocation of the part numbers.
- ✳ 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: ***E3*** → The number denotes the part (or tab of the part) that will be glued in this place. On some grey areas you will find the symbol ↻. This means that the part will be glued to itself on this area. 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.
- ✳ 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 a nail file or with our AstroMedia File Set (400.SBF). If a part has holes, don’t forget to open those before you fit it. Sometimes the “holes” are actually parts themselves (denoted with their own part number), so make sure you don’t throw those away.
- ✳ It is advisable to press large parts against a flat surface after glueing, to make sure they won’t warp.
- ✳ All folding lines are prepared by groves or perforations. If they are to be bent "forwards", you have to fold them towards you when looking at the gold and black 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.
- ✳ **Important: The segment discs and Leyden jars of this Wimshurst Machine are specifically calculated to make sure that the maximum power of the sparks stays far below the safe limit. Nevertheless, please read the safety hints at the end of these instructions**

Building Instructions

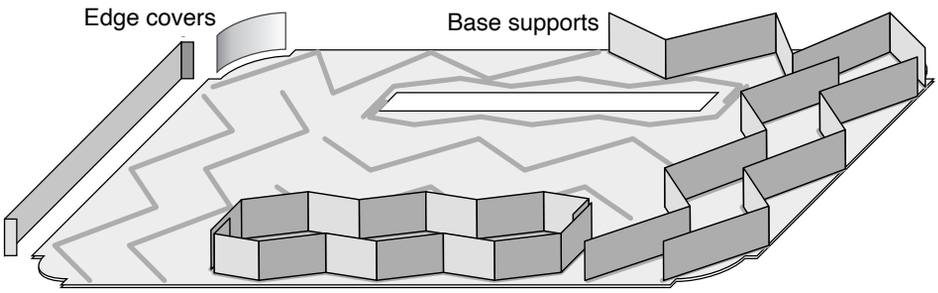


Fig. 1: Base top, upside-down

Chapter A

The Base

Top and bottom of the base consist of two layers of cardboard. The rest of the total height of 18mm of the base is made up of twelve upright cardboard supports that are folded in a zig-zag fashion. With these supports, the base has nearly the stability of a wooden board, but is much lighter. The rectangular cutouts in the top will later receive the two stands.

Step 1: Remove the cutouts for the stands from the two parts of the base top [A1, Sheet 1] and [A2, Sheet 2]. Glue the two parts exactly on top of each other as indicated by the glue markings. Do the same with the two parts of the base bottom [A3, Sheet 3] and [A4, Sheet 4].

The grey zig-zag lines indicate the positions for the base supports. The four shorter supports around the cutouts will be glued in first. The folds are prepared by perforations.

Step 2: Fold the two supports [A5, Sheet 1] and [A6, Sheet 2] twice backwards from both ends and then at the other fold lines in a zig-zag fashion. Stand the supports, first without glue, on the grey glue marks on underside of the base top [A1+2] around the stand cutouts and check that they are folded correctly. Next glue the ends of the supports together to form a crinkly rectangle and fit this around one of the cutouts using a fair amount of glue. Press the support against the base while the glue sets to make sure it fits without a gap.

Step 3: Repeat the last step with the supports [A7, Sheet 3] and [A8, Sheet 4] and glue them around the other cutout.

Step 4: Fold the eight supports [A9 to 12, Sheet 3] and [A13 to 16, Sheet 4] in a zig-zag fashion. Then glue them onto the remaining glue lines on the inner side of the base top. Again press the supports against the base top while the glue sets, e.g. by weighing them down with a book.

Step 5: Speedily apply a fair amount of glue to the edges of all supports and place the base bottom [A3+4] on top. Make sure that the edges of bottom and top are exactly flush by pushing them against your work surface while standing the base exactly upright. Then turn the base around and put it on your worktop the right way up, so that the glue can make a good connection between the parts. Weigh the base down with a book until the glue has set.

Now only the edge covers are missing to complete the base. They are all on Sheet 11 and will be glued directly onto the edges of the base bottom and top. First we apply the round corner pieces, then the four straight ones with the angled ends.

Step 6: Bend the edge cover [A17, Sheet 11] to a round shape by winding it around one of the aluminium tubes. Hold it against one of the corners of the base and check the fit. If it is too long, cut off a narrow strip. Then give the edges of the back of the edge cover a generous coating of glue and place it in its corner, covering the edges of the base top and bottom. Remove any excess glue. When the glue has set, repeat the process with the other three corner covers [A18 to A20, Sheet 11].

Step 7: Fold both end pieces of the edge cover [A21, Sheet 11] sharply backwards and then hold the strip against one of the shorter edges of the base to check the fit. If necessary correct the position of the folds and/or the length of the strip. Glue the edge cover in place the same way as the ones in Step 6. Do the same with the edge covers [A22 to A24, Sheet 11].

This completes the base.

Chapter B

Stand 1

*The two stands 1 and 2 receive their stability by the same principle as the base: between the front and rear sides, each made from two sheets of cardboard, we will glue zig-zag supports (*see *Fig 2). In the front sides of both stands are cutouts, the lower one for the PVC bearings of the drive shaft and the upper one for the cover that allows access to the axle thread. This is needed in case you need to replace one of the drive belts.*

Step 8: Remove the outer [B1, Sheet 5] and inner front side [B2, Sheet 6] from the cardboard. From these remove the parts [B22, B24] and [B23, B25], respectively and put them to the side. Glue both front side parts on top of each other.

The cover for the axle is only needed at the very end, but since it might need some adjustment (which is easier to do now), we shall construct it now.

Step 9: Glue the two parts of the lid of the cover [B20, Sheet 7] and [B21, Sheet 8] exactly on top of each other. Do the same with the two round parts [B22, B23] and the two latch parts [B24, B25].

Step 10: Glue the round part onto the back of the lid and then glue the latch on top of the round part. This is done most accurately by pushing a sewing pin through the small hole in the middle of all three parts when glueing them together. Take care that no glue is squeezed out of the edges. Let dry thoroughly.

Step 11: Slightly bend up the “wings” of the latch, so they can slide behind the stand wall and push the latch through the hole in the top of the stand front side. If the fit is too tight and/or you can’t turn the fastening, you need to widen the hole slightly. It is best to do this with a rolled up piece of sandpaper or a bent cardboard file of our file set. It might also be helpful to file down the latch as well. Once you are happy with the operation of the axle cover, take it out again and save it for later.

Important: The diameter of the holes in the PVC discs should be exactly 6mm. Due to variations in production, it is possible that the holes are slightly smaller. Check that all bearing disks fit smoothly onto the aluminium tubes. If necessary you can easily widen the holes by gently twisting a screwdriver or the blade of a small pair of scissors inside.

Step 12: To prepare the lower cutout for the PVC bearing, we first glue the inner bearing holder [B4, Sheet 6] onto its glue mark (don't forget to remove the small cardboard disc in the centre). Then a PVC bearing disc is pushed into the recess with some glue (superglue works quite well) and finally covered with the outer bearing holder [B3, Sheet 5].

Step 13: Remove the cardboard from the small holes in the outer [B5, Sheet 7] and inner rear side [B6, Sheet 8] and glue the parts on top of each other.

Step 14: Fold the eight supports [B7 to B14, Sheet 1 and 3] in a zig-zag fashion and glue them onto the back of the front side of the stand - the one that already holds the bearing disc. Try to glue the supports as accurately as possible onto the grey glue markings. Press the supports against the side of the stand while the glue sets. Then speedily apply a generous amount of glue to the edges of the supports and place the rear side of the stand on top. Again make sure that the edges of the sides are exactly flush. Lay the stand on the work surface with the rear side facing down and weigh it down with a book until the glue has set.

Step 15: Bend the printed end of the edge cover [B15, Sheet 11] backwards and test its fit on one of the lower edges of the stand. The white end should start at a bottom corner, the other end reaching to the top of the foot of the stand. Now glue it in this position and repeat the step with edge cover [B16, Sheet 11].

Step 16: Fold the ends of edge cover [B17, Sheet 11] sharply backwards and bend the strip just behind the longer end piece forwards to shape it like the upright part of the stand. Check the fit and adapt the position of the folds and the length of the strip if necessary. Then glue the edge cover onto the edge of the stand. Repeat the step with the other edge cover [B18, Sheet 11]. *Hint: the rounded edge cover for the head of the stand will be fitted after mounting the axle.*

Chapter C

Stand 2

The second stand is identical to stand 1 except for the round edge cover [C19, Sheet 11] for the head of the stand. The part numbers are identical too, except that they all start with a "C" instead of "B".

Step 17: Glue the outer [C1, Sheet 5] and inner front side [C2, Sheet 6] on top of each other. Also construct the axle cover from the removed parts [C22 + C23], [C24 + C25], and the lid parts [C20, Sheet 7] and [C21, Sheet 8] as described in Steps 9 and 10. Follow Step 11 to make sure the axle cover fits into the stand.

Step 18: Fit a PVC bearing disc with the help of the bearing disc holders [C3, Sheet 5] and [C4, Sheet 6]

Step 19: Glue the outer [C5, Sheet 7] and inner rear side [C6, Sheet 8] on top of each other. Fold the supports [C7 to C14, Sheet 2 and 4] in a zig-zag fashion and glue them onto the glue markings on the inner front side. Then glue the rear side on top of the supports as you did with stand 1 in Step 14.

Step 20: Glue the edge covers [C15 to C18, Sheet 11] onto the stand, following the instructions of Steps 15 and 16.

Step 21: Without glue, put the stands into their respective cutouts in the base, the sides with the bearing discs facing outwards. They should have a tight fit and reach right to the bottom of the base. If the cutouts are too small, you can file them slightly larger. It doesn't matter if the edges become a bit frayed because they will be covered with a sleeve later.

Chapter D

The Traverse

The traverse is made from insulating 4mm acrylic glass that is screwed to the head of one of the stands. It is rounded at both ends with 2.5 mm diameter holes. These will later take the current collector electrodes through which the electric charge is collected from the segments to be stored in the Leyden jars. Right next to the small holes are 5 mm holes for the pivots of the spherical electrodes. The electrical connections are made with pieces of aluminium foil. To make sure the arms of the spherical electrodes will retain their chosen angle, we will glue cork discs with a slightly smaller hole behind the 5mm holes. The traverse will only be screwed in at the end.

Step 22: The cork discs will be covered with cardboard around the edge and on one side for optical reasons. Bend the cork edge cover [D3, Sheet 11] round and glue it around one of the cork discs. Glue the cover [D5, Sheet 5] onto one side of the disc. Repeat these steps with the other cork disc and the covers [D4, Sheet 11] and [D6, Sheet 5].

Step 23: Remove the protective film from both sides of the acrylic traverse. It helps if you lift up the film with the tip of a knife at one corner. Glue the two cork disks with their bare sides over the two 5 mm holes, both on the same side of the traverse. The holes in the cork and the acrylic must be exactly concentric. It is best to use superglue for this because it sticks better to the acrylic.

Step 24: Glue the conductive strips [D1-Alu] and [D2-Alu] onto the other side of the traverse. They fit exactly over the round parts at the ends and connect them electrically. The holes in the acrylic will be covered by the aluminium.
See hints about working with the self-adhesive aluminium foil on the next page!

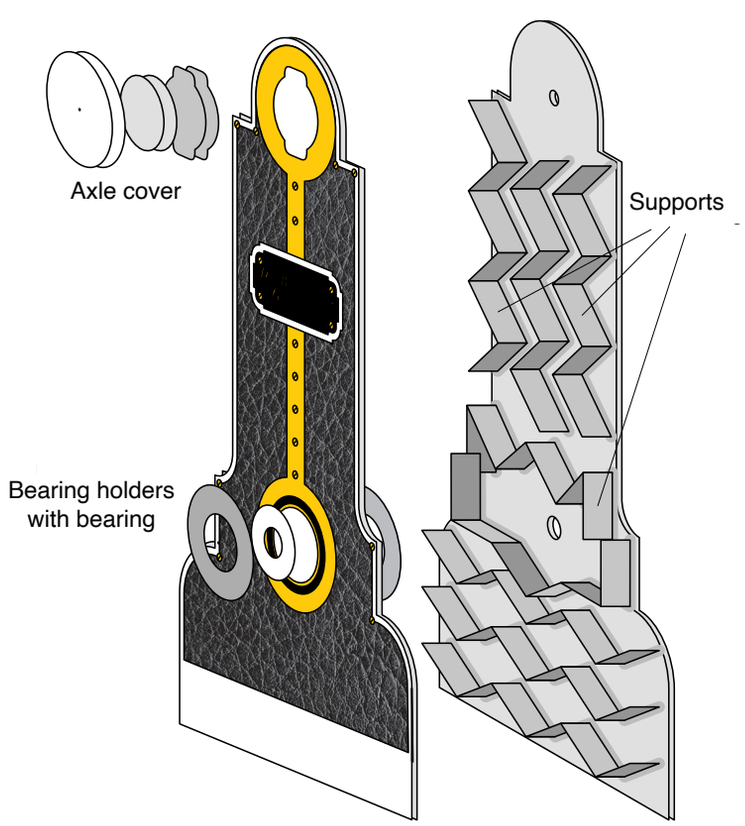


Fig. 2: The stand

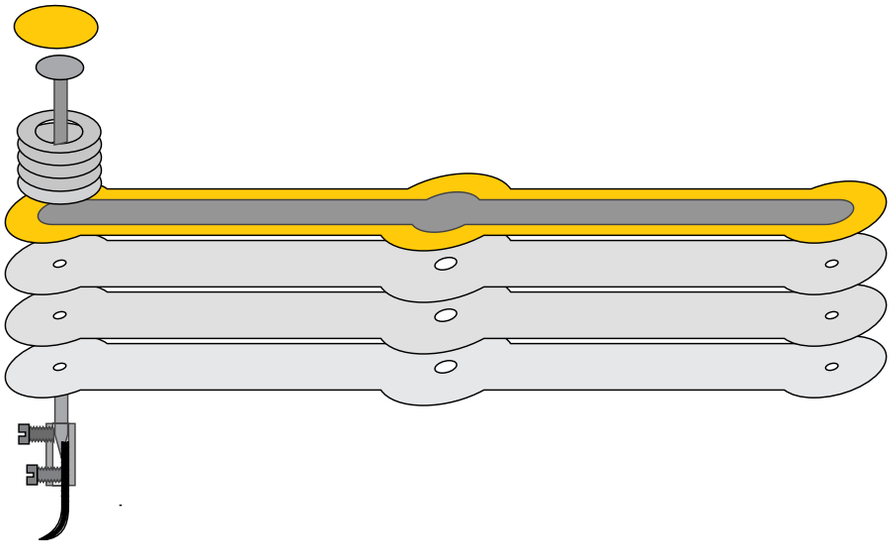


Fig 3: The neutraliser bar

Tips for working with the pre-punched self-adhesive aluminium foil:

1. *Identify the part you need with the help of the diagram at the end of the instructions.*
2. *Bend the backing film backwards along one of the punch lines and lift the edge of the part with the help of a knife. Then pull it off the backing film, taking care not to tear it.*
3. *Pull it straight if necessary and first stick on only one small corner. Then bring the rest into line and smooth it into place, trying to avoid bubbles and folds. Bubbles can be punctured with a needle and then smoothed out. Folds don't affect the function, only the appearance.*
4. *If an aluminium strip tears apart, you need to "bridge" the gap. Since only the silver top side conducts the current and the adhesive side is insulating, you need to do this with the following trick: Cut out a fitting piece from the leftovers of the aluminium sheet, lift it off the backing film, and fold small strips at the ends fully backwards so that the conducting top of the piece continues to the underside. If you now stick the piece over the tear, the folded-over strips make a flawless electrical connection because aluminium touches aluminium directly.*

Chapter E

Neutraliser Bar 1

*The neutraliser bars (*see *Fig 3) are the bars that are mounted at an angle in front and behind the segment discs. At their ends are electrodes with collector brushes that are connected by a conductor made from aluminium foil. This way the neutraliser bar can neutralise the charge between two segments on opposite sides of the segment disc. The brushes are connected to the electrodes by the inserts of the terminal connector strip. The electrodes are made from roofing nails. The finished neutraliser bars are mounted to the other components at a later stage. Since both neutraliser bars are identical, you can work through Chapter F at the same time.*

Step 25: Glue the inner parts [E1 and E2, Sheet 2] on top of each other and then glue the front [E3, Sheet 1] and rear [E4, Sheet 1] sides onto them. Press the part lightly while the glue sets.

Step 26: Stick the aluminium conductor strip [E5-Alu] onto the bar and smooth it flat. It will cover the two holes at the ends.

Step 27: Glue the four disc shaped nail holders [E6 to E9, Sheet 1] on top of each other to form a round stack and on top of this the ring-shaped nail holder [E10, Sheet 1]. Now push one of the roofing nails through the holder so that the head sits inside the ring-shaped part. It helps pushing the nail head against the work top to seat it properly. Push the nail through the aluminium foil and into one of the holes at the end of the neutraliser bar and glue the nail holder in place. The close contact between nail and aluminium makes for a good electrical connection. Make sure the nail sticks out at right angles. Glue the nail cover [E11, Sheet 5] on top of the nail head.

Step 28: Repeat the last step with the nail holders [E12 to E16, Sheet 1], a further nail, and the nail cover [E17, Sheet 6]. Fit this nail to the other side of the neutraliser bar.

Step 29: Remove the six inserts from the terminal strip. For this you have to remove the screws temporarily. Unscrew them completely and use the screwdriver to lever them out of the plastic (which is actually designed to secure them inside). The brass inserts can then be pushed out sideways.

Step 30: Screw the screws back into the inserts, one only a couple of turns, the other one fully. Then cut the copper wire into 6 pieces of equal length, about 2.5cm, and put each piece into one of the inserts, deep enough so it touches the fully screwed in screw. Then the wires stick out by about 17mm. Fasten them in this position with the other screw.

Step 31: To turn the ends of the wire into collector brushes, they need to be frayed to a length of a few millimetres so they look like a paint brush.

Step 32: Unscrew the fully inserted screws on two of the brass inserts a bit and push each insert over the ends of the nails in the neutraliser bar until the nails touch the other screw. Then fasten them in this position. Put the other collector brushes on the side.
This finishes the construction of the first neutraliser bar.

Chapter F

Neutraliser Bar 2

The second neutraliser bar is identical to the first one, as are the part numbers, except that they start with an "F".

Step 33: Glue the inner parts [F1, Sheet 6 and F2, Sheet 8] on top of each other and then glue the front [F3, Sheet 5] and rear [F4, Sheet 7] sides onto them. Also stick the aluminium conductor [F5-Alu] onto the front side.

Step 34: Construct the two nail holders from the parts [F6 to F10, Sheet 2] and [F12 to F16, Sheet 2], glue both with their nail onto the ends of the neutraliser bar and cover them with the parts [F11, Sheet 7] and [F17, Sheet 8]

Step 35: Fit a collector brush to each of the nails.

Put the neutraliser bars to the side, they will be needed later.

Chapter G
The Calibration Bench

The calibration bench is used to adjust the segment discs and the driving wheels to exactly right angles with respect to their axles.

Step 36: Remove the small square from the bottom plate [G1, Sheet 10] and fold the side walls [G2 and G3, Sheet 10] sharply forwards along the first groove line and backwards along the other ones. Put the bottom plate onto your work surface and glue the side walls sideways onto their respective glue markings (see *Fig. 4*). Push the side walls against the bottom plate until the glue has set to make sure they sit gap-free on the bottom plate.

Step 37: Remove the round disc from the centre of the first top plate [G4, Sheet 10]. Apply a generous amount of glue to the edges of the side walls and put the top plate on top, keeping it as parallel to the bottom plate as possible. Turn the bench over so that the glue can flow onto the plate and put a light weight on top while the glue sets.

Step 38: Underneath the bottom plate are eight glue markings for the feet. Glue two of each feet parts [G6 to G21, Sheet 10] on top of each other before glueing them onto these markings. Then put the bench on its feet.

Step 39: Remove the small square from the second top plate [G5, Sheet 10] and push the longer of the two aluminium tubes about a couple of inches through the hole. It is a deliberately tight fit, to make sure the tube is held in place. Now stick the end of the tube through the round hole in the top of the bench and finally also through the small quadratic hole in the bottom plate of the bench. Then push the second top plate down onto the first one and roughly align it with the grey glue marking, which is rotated by 45º. It is not glued in place yet.

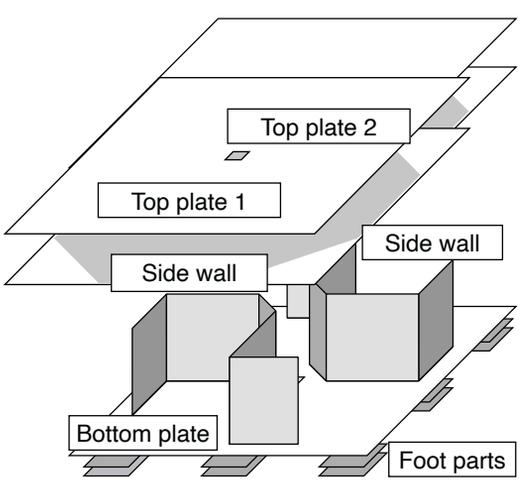


Fig. 4: The calibration bench

Step 40: The aim is to carefully move the second top plate around, until the aluminium tube sticks out at exactly right angles and then glue the plate in place. For this, stand a small set square on the plate and hold it against the tube and move the plate until the angle of the tube is exactly 90º. Take a clothes-peg and fix the plate in this position. Now turn the bench by 90º and repeat the procedure. Do this as often as needed, until you are satisfied that the tube stands at 90º from all sides. Lift one corner of the second top plate, apply a little glue underneath, and press it down with another clothes-peg until the glue has set. Then glue the other sides down as well. Leave the tube in the holes for the time being.

Chapter H
The Segment Discs

The segment discs are made from 2 mm acrylic glass, onto each we will glue 24 aluminium foil segments.

Step 41: Check for burrs at the ends of the aluminium tubes and file them off if there are any. For the outside a file or sand paper are ideal, for the inside you can use the thread rod provided with this kit. Take the shorter tube and check that it fits through the central holes in the segment discs. If necessary you can widen the holes with a piece of rolled up sand paper or a small round file to make sure the discs turn freely on the tube.

Step 42: Remove the protective film from both sides of one disc and stick it on top of the segment pattern at the end of the instructions with some sticky tape. The hole in the middle must be exactly on top of the circle in the centre of the pattern. (The pattern at the bottom of the page will be used later for the Leyden jars)

Step 43: Stick the 24 aluminium foil segments [H1-Alu to H24-Alu] onto the places indicated by the pattern. Smooth them down as flat as possible.

Step 44: Repeat the last step with the other disc and the segments [H25-Alu to H48-Alu].

Chapter J
Hub 1

A hub consists of a round cardboard cylinder which is glued to a segment disc on one side and holds a PVC bearing disc on the other. On the outside of the cylinder it carries two rings which form the rims for the driving belt. The second hub is identical, so you can work through Chapter K at the same time, if you want.

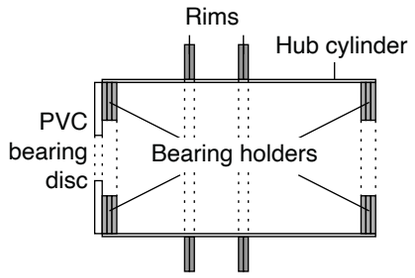


Fig 5: Cross section of the hub

Step 45: Bend the hub cylinder [J1, Sheet 11] round and glue one half of the connecting piece [J2, Sheet 11] behind one side of the cylinder. It is narrower than the edge of the cylinder and should be glued on centrally. Once the glue has set, glue the other half of the connecting piece behind the other edge of the cylinder. The cylinder edges should be flush without gap.

Step 46: Glue the inner and outer part [J9 and J10, Sheet 9] of the first rim back to back, do the same with the ones of the other rim [J11 and J12, Sheet 9]. Push the rims onto the cylinder and glue them onto the grey glue markings using a few drops of glue on the inside. Check that the rings are at right angles to the axis and that their distances to the edges of the cylinder are 11 and 17mm respectively.

Step 47: Glue the three bearing holder parts [J3 to J5, Sheet 9] together to form a stack, do the same with the parts [J6 to J8, Sheet 9]. Glue the stacks into the ends of the hub, so that they are exactly flush with the edges. If one stack has slid in too far, you can stand the hub on your worktop and push the stack in position with a screwdriver from the other side.

Step 48: The rims are not in the centre of the hub, but shifted to one side. Stand the hub upright on our work surface with this side facing down (the longer part facing upwards). Put one of the segment discs on top of the hub with the aluminium segments facing down. The hole in the centre should be exactly in the centre of the bearing holder. Fit the disc in this position using superglue. **Important: the hub is glued onto the side that holds the segments!**

Step 49: Turn the disc around again and slide it over the tube in the calibration bench. The segment disc is now lying on top of the bench, the hub on top, and the tube sticking out of the hole in the hub. Now take a PVC bearing disc, slide it over the aluminium tube, and glue it on top of the hub with superglue. Since the tube is at right angles to the bench and the disc, the bearing will be in exactly the right place to make sure the disc will turn without wobbling.

Chapter K

Hub 2

Construct the second hub the same way as the first one.

Step 50: Glue the hub cylinder [K1, Sheet 11] together using the connection piece [K2, Sheet 11].

Step 51: Construct the rims [K9 and K10, Sheet 9] and [K11 and K12, Sheet 9] and glue them in place on the hub.

Step 52: Make the two bearing holders from the parts [K3 to K5, Sheet 9] and [K6 to K8, Sheet 9] and glue them into the ends of the hub.

Step 53: Glue the hub centrally onto the side of the other segment disc that holds the segments. Make sure that the segments face the side with the hub.

Step 54: Using the calibration bench as in Step 49, glue a PVC bearing onto the other end of the hub.

Chapter L

The First Driving Wheel and The Preparation of The Leyden Jars

The driving wheels are both fitted to the drive shaft and have a considerably larger diameter than the hub. This gearing allows for a higher rotational speed of the segment discs. The inner supports of the wheels [L3 and L4, M3 and M4, Sheet 9] are also used as tools for the construction of the Leyden jars. Therefore we will bring forward the first steps of their construction. The Leyden jars are each made from a 105 x 297 x 0.3 mm piece of PVC that is rolled into a tube of 33 mm outer diameter, so that the PVC acts as triple insulating barrier. To turn this tube into a Leyden jar (a capacitor), we need to apply electrodes made from aluminium foil on the inside and outside, that are exactly opposite each other. The capacity of the capacitor, its ability to store electrical charges, depends on the surface area of its electrodes as well as on the distance between them. Our Leyden jars together have a capacity of about 20 pF (pico-farad). At a voltage of 70,000 V this limits the maximal available energy to 49 mJ (millijoule) which is only 14 % of 350 mJ, the upper limit considered non-hazardous.

Step 55: Fit the end of one of the PVC pieces over the glueing pattern at the end of the instructions (underneath the one for the segment discs) and secure it with some sticky tape. Then stick the inner electrode [O1-Alu] onto its designated place. Check that its distance from the edges is 30 and 35mm as shown on the pattern. Do the same with the other PVC piece, using the electrode [P1-Alu].

Step 56: Glue the two inner supports [L3 and L4, Sheet 9] of the first driving wheel on top of each other. Do the same with the ones for the second driving wheel [M3 and M4, Sheet 9]. These two rings are the tools that define the outer diameter of the Leyden jars.

Step 57: Roll one PVC piece into a tube so that the aluminium electrode is on the inside of the tube (not between the layers) and push the two rings over it. Slide the rings inwards until they sit right over the edge of the electrode. Now push the tube against your work surface to make sure that the edge of the tube is straight. If the inner layer is arched inwards a bit, push it back and secure it with some sticky tape.

Step 58: Push the rings about 1 cm outwards and wrap the outer electrode [O2-Alu] around the tube, exactly over the inner one. Start at one end and pull the aluminium foil straight when sticking it to the tube. It reaches once around the whole tube. Any folds or creases can be smoothed down nicely by rubbing the foil with one of the aluminium tubes.
In principle the Leyden jar is now a fully functioning capacitor, only the connection strips are missing.

Step 59: Push one of the rings to a position about 1cm from the edge and the other one a small distance apart. The outer and inner corners of the PVC sheet need to be glued down because they don't stay in place on their own. Use a small drop of superglue under each corner and press them together with clothes-pegs. A piece of sticky tape does the trick as well. Afterwards push the rings to the other edge and glue down the other corners. *Attention: Take care that the peg doesn't come in contact with the glue.*

Step 60: Repeat Steps 57–59 with the other PVC sheet to construct the other Leyden jar. Put both jars on the side for later.

Now we carry on with the first driving wheel.

Step 61: Remove the Leyden jar bottom lid [O5] from the inner rim [L2, Sheet 5] and put it on the side. Glue the inner rim onto the outer rim [L1, Sheet 9] and then the inner supports [L3, L4] (one of the tools for the Leyden jars) on top of that.

Step 62: Push the rim with the supports onto the calibration bench with the supports pointing up. Now glue the twelve hub discs [L5 to L14, Sheet 5] and [L15 and L16, Sheet 7] onto the rim by threading them one by one onto the tube sticking out of the bench.

Step 63: Bend the running surface of the wheel [L17, Sheet 11] round by drawing it over the edge of a table. Apply a thin line of glue into the corner between the outer and inner rim and glue the running surface in place, overlapping the ends and glueing these together as well. Push the running surface well down into the corner, so that the upper edge has about the same height as the central hub. If the hub is far too low, you can cut a fitting piece of paper or cardboard and glue it on top.

Step 64: Glue the two parts [L18, Sheet 9 and L19, Sheet 7] of the second rim on top of each other. On the inner rim, apply a thin line of glue on the glue marking for the running surface and a normal amount on the glue marking for the hub. Then fit the second rim on the tube in the calibration bench and push it down onto the rest of the wheel. Take the driving wheel off the tube once the glue has set by gently rotating and pulling at the same time.

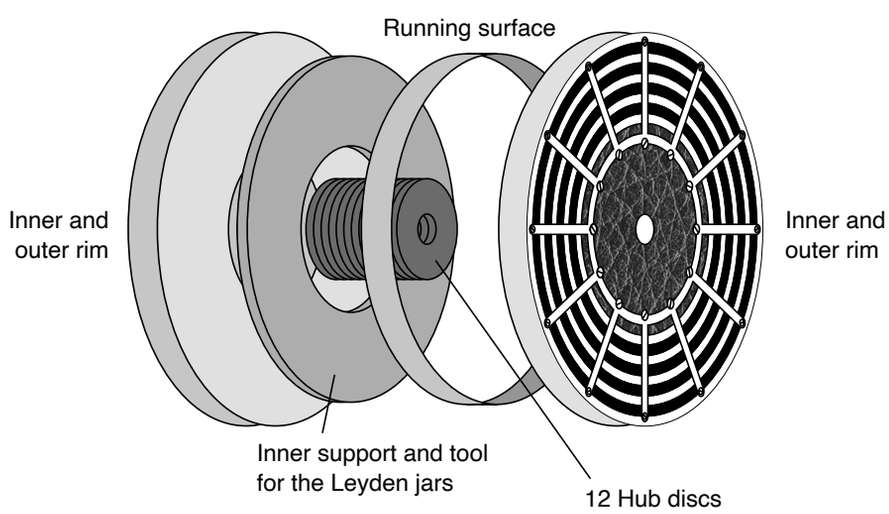


Fig. 6: The driving wheel

Chapter M

The Second Driving Wheel

Construct the second driving wheel the same way as the first one.

Step 65: Glue the outer [M1, Sheet 6] and inner rim [M2, Sheet 6] on top of each other and then glue them onto the inner support [M3, M4].

Step 66: On the calibrating bench glue this rim, the twelve hub discs [M5 to M14, Sheet 6] and [M15 and M16, Sheet 8], and the running surface [M17, Sheet 11] together.

Step 67: Glue the outer [M18, Sheet 9] and inner [M19, Sheet 8] second rim on top of each other and these then onto the other parts of the second driving wheel which is still on the calibrating bench.

Now both driving wheels are ready to be fitted to the drive shaft.

Step 68: After carefully pulling the driving wheel off the bench, clean the long aluminium tube from any glue residue. This long tube (127 mm) is going to be the drive shaft. Push both driving wheels onto the tube again so that one has a distance of 38.5 mm to the end of the tube, the other one a distance of 32.5 mm to the other end. The distance between the wheels should now be about 39.5 mm. Glue them to the tube in this position.

Hint: since superglue sets too quickly and doesn't leave any margin for error, it is advisable to use normal glue for this; or 2-component glue if your normal glue isn't strong enough. The glue sticks better, if you roughen the aluminium tube under the wheels, using sandpaper. The same hint applies to the fitting of the crank in Step 76.

Chapter N

The Crank

The crank consists of two parts, each made from four layers of cardboard, and is therefore very strong (see Fig. 7).

Step 69: Glue the two middle parts [N2, Sheet 6] and [N3, Sheet 8] of the lower crank part exactly flush on top of each other, then on this the two outer parts [N1, Sheet 5] and [N4, Sheet 7].

Step 70: Glue together the four parts [N6, Sheet 6], [N7, Sheet 7], [N5, Sheet 5], [N8, Sheet 8] of the upper crank part in the same way and afterwards on top of the lower part. Take care that the holes are exactly flush. The 6 mm hole will later take the drive shaft, the 5 mm hole at the end of the crank will take the axle of the handle. Without glue, test the fit with the aluminium tube and the wooden shaft and check that they are at right angles to the crank.

Step 71: Glue the reinforcement rings [N9 and N10, Sheet 7] onto the front over the larger hole. Then glue the reinforcement rings [N11 and N12, Sheet 8] onto the back.

Step 72: In the same way glue the reinforcement rings [N13, Sheet 6] and [N14, Sheet 5] onto the front side over the smaller hole. Push the 40 mm long wooden axle so far into this hole, that its end is flush with the surface of the back of the crank and glue it in place. Then cover the end of the axle by glueing the cover [N15, Sheet 6] on top.

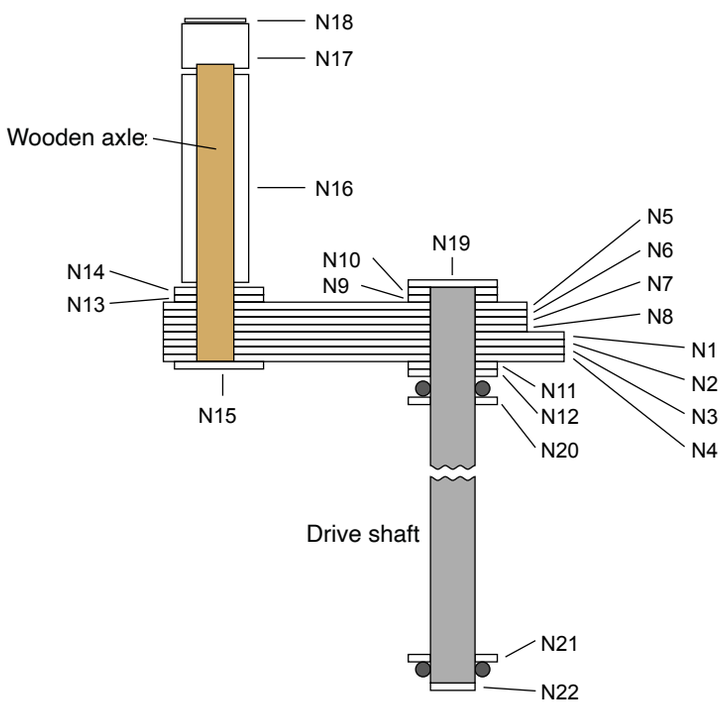


Fig. 7: Cross section of the crank

Step 73: Bend the sleeve [N16, Sheet 11] round so that it fits around the wooden axle. To make sure it will rotate freely on the axle, we use the following trick: wind a 5cm wide piece of thin paper once or twice around one of the long wooden shafts and secure it with some sticky tape. First without glue, wind the sleeve around the paper, so that the print of the three little screws is on the outside. The edges of the sleeve should be as flush as possible. Then glue the sleeve together, making sure that it doesn't stick to the paper underneath. Once the glue has set, pull it off and put it on the axle of the handle. The axle will stick out by about 6–7mm. If the sleeve ends are not completely even, you can file them down a bit or cut off the bits that are standing out. The overall length of the sleeve should be 18 mm.

Step 74: Bend the narrow strip of the sleeve retainer [N17, Sheet 11] round and glue the grey end to the end of the wooden axle. Then glue and wind the strip around the axle so that its upper edge is flush with the end of the axle. Now the sleeve is secured in place but can still turn around the axle. Finally glue the cover [N18, Sheet 11] on top of the axle end.

Step 75: Take the drive shaft with the two driving wheels and the second stand [C1, C5]. Push the longer end of the drive shaft through the lower hole on the inside of the stand so that it protrudes from the PVC bearing on the other side. Now push the washer [N20, Sheet 7] over the protruding end of the drive shaft, followed by one of the O-rings. This secures the shaft to the stand. The washer keeps the O-ring from rubbing on the PVC bearing.

Step 76: Now push the crank onto the protruding end, so that the end of the axle is flush with the surface of the top reinforcement ring. Glue it into this position, but make sure that it is at right angles to the axle and that it doesn't wobble when it is turned round. Finally glue the cover [N19, Sheet 5] over the end of the axle and push the axle back in, so that the crank is as close as possible to the stand (but still turns easily).

Step 77: Push the other end of the drive shaft through the other stand, so that it sticks out from the PVC bearing. Push the washer [N21, Sheet 8] over the end of the shaft and finally also the other O-ring. The O-ring should sit right next to the end of the shaft, so that you have enough free movement for the assembly. Glue the cover [N22, Sheet 11] over the hole of the drive shaft.

Intermediate Step

Assembly Of The Finished Parts

We will now put together the components we have finished so far, to make up the basic construction of the Wimshurst Machine. A threaded rod with metal washers and nuts makes sure that the axle is securely fixed between the heads of the stands. At the same time it holds the traverse and the neutraliser bars. The Leyden jars and the spherical electrodes will be fitted later.

Step 78: Put the two connected stands into their rectangular holes in the base. The stand holding the crank belongs on the side that has the narrower rim, opposite the side with the grey glue marks for the Leyden jars (O3 and P3). Since the stands are not glued in yet, their heads can be pushed apart, which helps the fitting of the axle.

Step 79: Remove all dust particles from the segment discs, especially from the sides without the segments because they won't be accessible after assembly. Then stick the 84 mm aluminium tube of the axle through the hub of one disc, through the last PVC bearing disc, and then through the other segment disc and its hub. The two segment discs are now only separated by the PVC disc and should barely touch each other. The axle sticks out about 1 mm on each side. Put the two 3 mm wide rubber bands between each pair of rims on the hubs. *If you find that the holes in the discs and the bearings have a different diameter, you should enlarge the smaller ones using a rolled-up piece of sandpaper.*

Step 80: Screw one of the nuts on one end of the thread rod, so that 3–4 threads are visible on the outside. If the nut is hard to fit onto the rod, check the end of the thread for burrs. These can be easily bent into shape with a knife. Secure the nut with a drop of superglue.

Step 81: Put a metal washer on the rod and then stick it from the outside through the top hole in the stand that holds the crank, until it protrudes about 1cm on the other side.

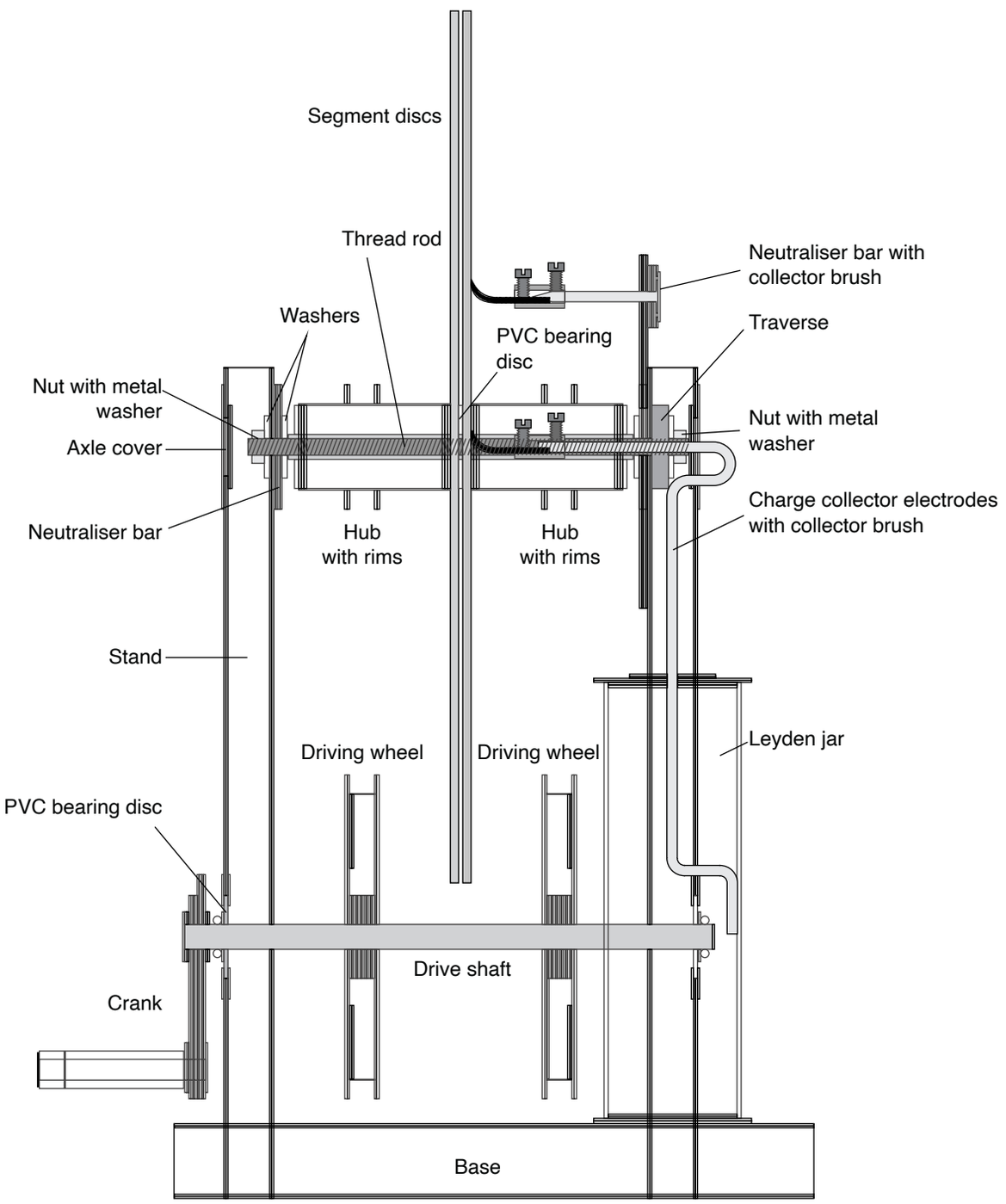


Fig. 8: Assembly cross section

Now push a neutraliser bar over the end of the rod, so that the brushes point inwards towards the other stand. Next add another metal washer.

Step 82: Take the section consisting of the segment discs, axle, and driving belts and hold it between the stands, so that you can push the end of the thread rod through the aluminium tube until it protrudes from the other end. Fit another metal washer and the other neutraliser bar with the brushes pointing inwards onto the rod. Then push the rod through the hole at the top of the other stand and secure it all with the other nut. Use small pliers or a 7 mm box spanner for this. Don't tighten the nut yet.

Apart from the traverse, all major elements of the machine are now in place: In the middle you have the two segment discs, which nearly touch, with the drive belts hanging from their hubs. The aluminium tube axle abuts against a metal washer on each side, and these each against a neutraliser bar, whose collector brushes touch the segment discs. When the nuts are tightened, the neutraliser bars are clamped between the washers and the stands. It is important that the bars are not glued in, since their angle needs to be adjustable. ***Important: For clockwise cranking, the neutraliser bars have to point from the top left to the bottom right when viewed from the outside.***

Step 83: Next, we need to pull the drive belts over the driving wheels. For this, remove the O-ring and the cardboard washer from the drive shaft and pull out the shaft from the stand opposite the crank. The resulting gap is just big enough to pull the drive belts through. Carefully pull the drive belt closest to the crank down, until you can pull it over the end of the drive shaft, over the first driving wheel, and finally onto its own driving wheel. Then pull the other drive belt down, twist it half a turn, pull it through the gap, and onto the first driving wheel. The half turn twist is very important, because it ensures that the segment discs will be counter-rotating although they are driven by the same drive shaft.

Step 84: Push the end of the drive shaft back through the hole in the stand and secure it in place with the cardboard washer and the O-ring. Adjust the two O-rings so that the drive shaft has no end play, the crank can be turned freely, and the driving wheels sit right underneath the hub rims.

Step 85: Remove the nut from the thread rod, pull the rod back slightly and place the traverse into the slot in the head of the stand with the cork discs facing the segment disc. Push the rod back through the hole in the traverse, fit the last metal washer, and secure it with the nut. Tighten the nut, but make sure that the neutraliser bars can still be turned up and down. Turn the crank clockwise and check that everything moves smoothly and that nothing jams or drags.

Step 86: Make sure that the walls of the stand heads are straight and parallel and cover the gaps with the covers [B19 and C19, Sheet 11]. One of the covers has a cutout to fit over the traverse. After the glue has set, fit the two axle covers that you made in Chapters A and B.

Step 87: Once more remove the stands from the base, apply a generous amount of glue to the bottom of the base inside the cutouts where the stand edges belong, and put the stands back in. Let the glue dry well.

Step 88: Fold the two foot sleeves [B25 and C25, Sheet 11] forwards along the long groove and backwards along the short ones. Try their fit around the feet of the stands. The wider part is fitted to the stand, the narrower one to the base. Glue them into this position.

Chapter O

Leyden Jar 1

The tubes of the Leyden jars are already made, only their bottom and top lids and the charge collector electrodes are missing. Each lid consists of two double layer cardboard discs with a diameter larger than the one of the tube and another set of two discs that fit just inside the tube. This way the jars become very rigid. The two Leyden jars are connected in series, so that each only receives half of the generated voltage. For this, we stick a strip conductor onto the base, which connects the outside electrodes of the jars with the help of two more strip conductors.

Step 89: Stick the strip conductor [O16-Alu] onto its glue marking on the base.

Step 90: Glue the two bottom lid parts [O3 and O4, Sheet 10] on top of each other, do the same with the slightly smaller parts [O5, Sheet 5] and [O6, Sheet 6], and then glue these two discs centrally on top of each other. Make sure that the bottom lid fits onto the tube so that the smaller discs slide fully inside.

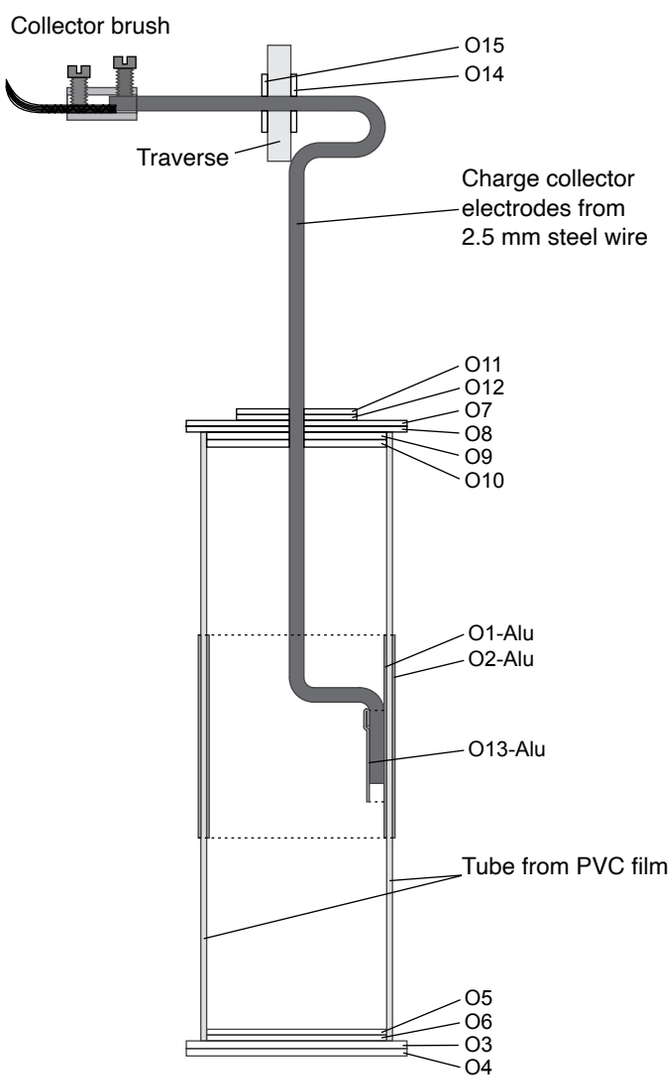


Fig. 9: Leyden jar

Step 91: In the same way glue on top of each other: the lid parts [O7, Sheet 7] and [O8, Sheet 8], the slightly smaller lid parts [O9 and O10, Sheet 10], and on top of all the even smaller parts [O11 and O12, Sheet 5 and 6]. Before glueing the parts together, remove the cardboard from the small holes in their centre through which the charge collector electrodes will be stuck later. The holes have to be exactly on top of each other. Make sure that the lid fits onto the tube so that the discs [O9] and [O10] slide fully inside. Then the smallest parts [O11] and [O12] are on top of the jar.

Before the lids are glued to the jar, we need to mount the charge collector electrode and fix it at the correct height:

Step 92: Take one of the charge collector electrodes and check the ends for possible burrs. If there are any, file them down with sandpaper or a file until the ends are smooth. The short lower end of the electrode is offset from its middle part by 14mm through two right angle bends. This end has to be connected to the inner electrode of the Leyden jar. To do this, push it from the top through the hole in the lid and glue the lid into one end of the tube with a few drops of superglue. Make sure that the smaller disks sit properly inside the tube. The electrode should still be loose inside the lid.

Step 93: Push the bottom lid into the tube as well, but don't glue it in yet. The Leyden jar now looks finished. Turn the charge collector electrode so that its lower end touches the middle of the electrode inside the tube. Now stand the jar in its place on the base of the machine so that the upper end of the charge collector electrode lies flat against the traverse. The aluminium foil on the end of the traverse covers 2 holes. The outer one has a diameter of 2.5 mm and takes the end of the charge collector electrode. The other one is bigger and is meant for the axle of the spherical electrode. Adjust the charge collector height so that the end will fit exactly into the small hole. Then fix the position of the electrode in the lid with a drop of superglue after checking again that the other end touches the electrode inside the tube. This is very important, because otherwise the charge can't be stored in the Leyden jar.

Step 94: To connect the lower end of the charge collector electrode permanently with the electrode on the inside of the tube, we will stick them together with the aluminium connection piece [O13-Alu]. To make sure we get a good electrical connection, we use the trick described in the yellow box on page 6: fold a narrow strip on one edge over and stick it to its back, so that along this strip both sides are conducting. The easiest way to apply the piece of foil is the following: Make a small tube of rolled up sticky tape with the glue on the outside, and stick that to the tip of a screwdriver or spoon handle. Then stick this to the outside of the aluminium foil and apply it in the right position. Remove the screwdriver and push the foil into place with your finger, making sure that you get a good contact between the electrodes. FInally glue the bottom lid into the tube.

Step 95: Make a small cut in the aluminium foil on the traverse where it covers the small hole. Push the small cover disc [O14, Sheet 5] on the end of the charge collector electrode and push the electrode through the small hole in the traverse until it sticks out by about 26mm on the other side. Check that the middle part of the electrode is perfectly vertical and parallel to the stand and glue the Leyden jar in its place on the base.

Step 96: Push the other cover [O15, Sheet 6] onto the upper end of the electrode, apply a drop of superglue on both sides where the electrode protrudes from the traverse and push both covers in place. Fit one of the prepared collector brushes to the end of the electrode.

Now we only have to connect the outer electrode of the Leyden jar with the connector strip on the base.

Step 97: Carefully remove the conductor strip [P16-Alu] from the backing film. On its ends it has two small cuts so that between those we get two little flaps that we fold backwards and stick to the back of the strip. This way the strip has its conducting surface on both sides. Stick one end of the strip onto the angled end of the strip that is already on the base. The other end then reaches to the middle of the Leyden jar, with the conducting flap connected to the outer electrode.

This finishes the construction of the first Leyden jar. The construction of the second one follows the same steps, only that all part numbers begin with a "P".

Chapter P

Leyden Jar 2

Step 98: Construct the bottom lid from the parts [P3 and P4, Sheet 10] and [P5, Sheet 7 and P6, Sheet 8]. Also glue together the parts [P7, Sheet 7 and P8, Sheet 8], [P9 and P10, Sheet 10], and [P11, Sheet 7 and P12, Sheet 8], to form the top lid.

Step 99: Remove the burrs from the other charge collector electrode and push its lower end through the top lid and glue the lid to the tube. Push the bottom lid into the tube and turn the charge collector electrode so that it touches the centre of the inner electrode of the tube. Adjust the charge collector electrode so that it has the same height as the small hole at the end of the traverse and fix it with a drop of superglue in the lid of the Leyden jar.

Step 100: Stick the aluminium connection piece [P13-Alu] onto the lower end of the charge collector electrode and the inner electrode of the Leyden jar. Glue the bottom lid into the Leyden jar.

Step 101: Push the cover disc [P14, Sheet 7] onto the upper end of the electrode, push the electrode through its hole in the traverse, and glue the Leyden jar in its place on the base. Push the other cover disc [P15, Sheet 8] onto the end of the electrode, apply some superglue to the hole in the traverse and push the cover discs in place. Fit the last collector brush to the end of the electrode.

Step 102: Make the electrical connection between the connector strip on the base and the outer electrode of the Leyden jar using the aluminium strip [O17-Alu].

Chapter Q

Spherical Electrode 1

The electrodes are constructed from wooden rods and spheres. To make them electrically conducting, they are lined with aluminium foil. The lower part of the rods will be insulated with shrink tube. The second electrode is identical to the first one, only the part numbers begin with an "R" instead of a "Q". If you want, you can construct both electrodes at the same time.

Step 103: Stick the aluminium part [Q1-Alu] onto one of the 180 mm long wooden rods. Start exactly at one end of the rod, so that 104 mm of the rod will be covered with aluminium. Smooth the foil down onto the rod; if you rub it with a pen, you can can get rid of all folds and make it nice and shiny.

Step 104: Each electrode takes two wooden spheres, one with a through-hole, one with a stud hole. Push the free end of the rod into the sphere with the stud hole and mark on the rod how far it goes in. Cut a length off the shrink tube that reaches exactly from this mark to the beginning of the aluminium foil. Push the tube onto the wooden rod and shrink it in place by holding it over a flame, moving it back and forth, and rotating it at the same time. Now the wooden rod is covered by aluminium foil and shrink tube, except for the small bit at the end that will be glued into the wooden sphere.

Step 105: Cover one of the 45 mm long wooden rods with the aluminium foil [Q2-Alu]. This rod will be the axle of the electrode. The aluminium foil has to extend over one end by about 2 mm to facilitate the electrical connection with the aluminium foil on the long rod. On the other end about 7 mm will remain uncovered. Push the protruding aluminium foil against the end of the rod.

Step 106: To connect the two rods we need a very stable bracket. For this, glue the six bracket pieces [Q5 to Q10, Sheet 9] exactly on top of each other to form a small block.

Hint: *The parts are numbered, but they are identical, so you can glue them together in any order.*

Glue the slightly larger pieces [Q11 and Q12, Sheet 7] on top and underneath the block, so that the curved sides are flush with the curved side of the block. The two straight edges then protrude by about 1mm. The resulting channels will house the wooden rods (see *Fig. 10*).

Step 107: In the same way construct a second bracket from the pieces [Q13 to Q18, Sheet 9] and the two larger pieces [Q19 and Q20, Sheet 7].

Step 108: Place the two blocks next to each other on your worktop with the axle in between (see *Fig. 10*). The axle then is housed in the longer channels of the brackets. The aluminium covered end of the axle needs to be flush with the channels of the shorter edges, to ensure proper electrical contact with the long rod that will be glued across. Glue the axle into this position using superglue. Make sure that no glue reaches the aluminium on top of the axle.

Step 109: Glue the long rod across the axle, so that the part in the channel is covered with aluminium and the edge of the foil and the beginning of the shrink tube is flush with the edge of one bracket. Again, make sure that no glue reaches the contact area between the two rods.

Step 110: Bend the centre of the bracket cover [Q21, Sheet 11] round, so it fits around the brackets and the two rods. Put it around the connection to check the fit and then glue it in place to secure it.

Step 111: Stick the aluminium cover [Q3-Alu] on the large wooden sphere with the through-hole. The cover consists of six connected segments that have to be wrapped around the sphere so that the tips of the segments come to lie over the holes of the sphere and are then pushed into the holes. Make sure that there are no gaps between the segments through which you can still see the wood. It is inevitable that the aluminium foil will crease, but these wrinkles can be smoothed flat because the foil is only 0.1 mm thick: put the sphere on a hard surface and roll it around, applying some pressure with your hand or a not too smooth board until the surface is nearly mirror-like. The smoother the surface is, the less corona discharges you will get and the stronger the sparks will be. Stick the tips of the foil firmly against the inside of the holes to ensure a good contact with the aluminium covered rod.

Step 112: Push the covered sphere onto the aluminium covered end of the electrode until about 5 mm stick out on the other side. Push one of the small spheres with a stud hole onto the end to check that it sits nicely against the large sphere.

Step 113: Stick the aluminium cover [Q4-Alu] onto the small sphere. The tips of the four segments should end over the hole in the sphere and should be stuck to the inside. Again try to smooth out as much of the creases as possible. Fit the sphere to the end of the electrode and secure both spheres with a drop of superglue. Only use a tiny amount on the wood inside the stud hole to make sure that the aluminium foils make good electrical contact. Now glue the uncovered large wooden sphere with the stud hole onto the other end of the electrode.

Step 114: Glue the electrode washer [Q22, Sheet 7] centrally onto the the other three [Q23, Sheet 1], [Q24, Sheet 6], and [Q25, Sheet 8]. Push the washer onto the electrode axle and then the axle through the hole on one end of the traverse. For this you first need to make a few small cuts in the aluminium foil covering the hole. Push the axle through until it sticks out of the cork disc by about 10 mm. Glue one of the small wooden spheres with a stud hole onto the wooden end of the axle so it can't be pulled out anymore. Pull the axle back as far as possible, push the block of washers back against the traverse and secure it with a drop of superglue on the axle (NOT on the traverse!).
Now the spherical electrode is secured in the traverse, but can still be rotated.

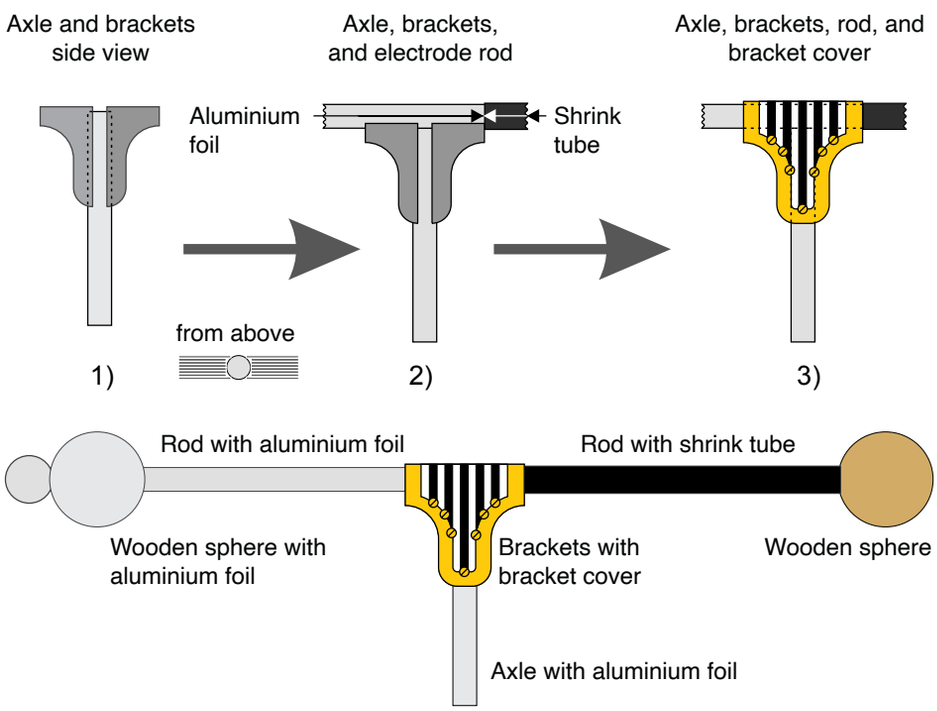


Fig 10: Spherical electrode

Chapter R

Spherical Electrode 2

Step 115: Construct the second spherical electrode in the same way as the first one. Glue together the electrode washer from the parts [R22, Sheet 7], [R23, Sheet 2], [R24, Sheet 6], and [R25, Sheet 8]. Push it on the axle and secure the electrode in the traverse with the last small wooden sphere and the washer.

Congratulations, now your Wimshurst Machine is finished! Please read the following hints for using the machine:

Chapter S

Operating Your Wimshurst Machine

1. Before operating your Wimshurst Machine, always check that all collector brushes are in contact with the segment discs.
2. Adjust the spherical electrodes to a distance of about 1 cm and rotate the crank clockwise until sparks appear. Gradually increase the distance between the electrodes to produce longer sparks. Try to experiment with the position of the electrodes; for example try aiming a small sphere at the large one on the opposite side. You can also vary the angle of the neutraliser bars until you find the position that produces the longest sparks. Remember: The steeper the neutraliser bars are, the higher the voltage, but the lower the current. A higher voltage will produce longer sparks, but if the current is too small you will lose too much charge through corona discharges, so that no spark will develop.
3. Operate the machine in dry conditions. Moist air will increase corona discharge and prevent long sparks.

Safety Instructions:

Never use your Wimshurst Machine close to inflammable gases or fluids! The sparks can ignite those and lead to an explosion.
Children should not be allowed to operate the machine without adult supervision. The sparks themselves are harmless because the current is restricted by the design of the machine. Nevertheless they can make you jump and might unexpectedly frighten children.

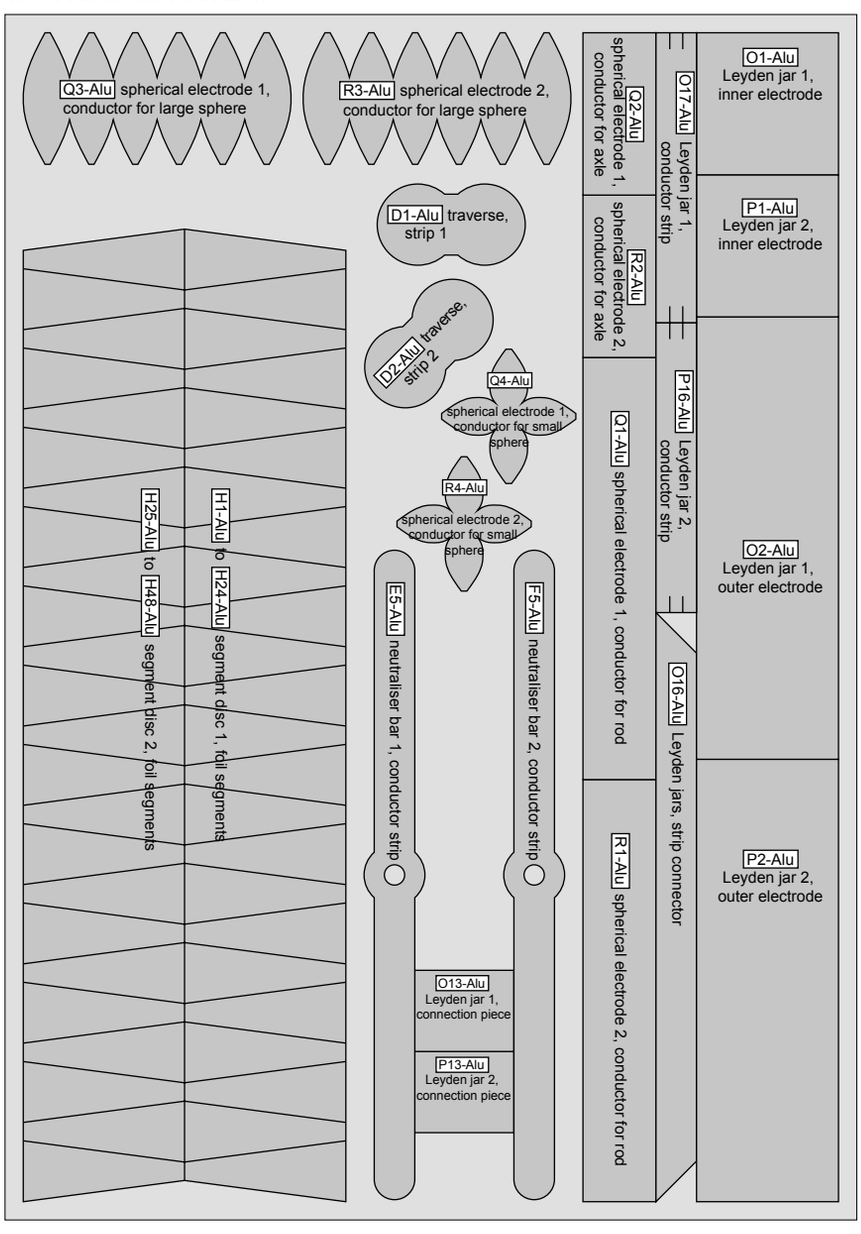
Questions and Answers

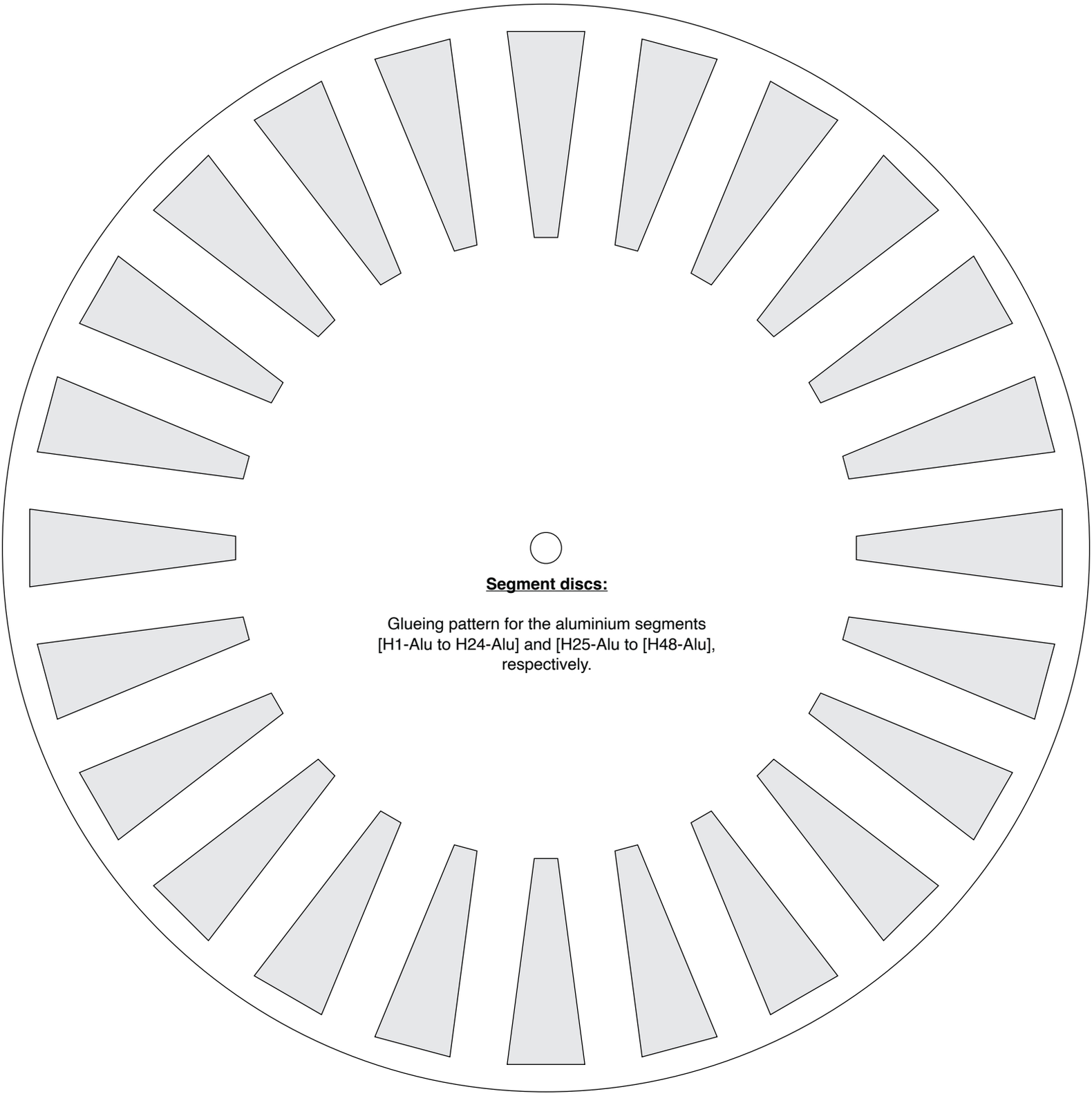
1. My machine doesn't produce any sparks. How can I make it work?
- Check that all six brushes are in contact with the segment disc.
- Check that both neutraliser bars are pointing from the top left to the bottom right and that you are cranking in a clockwise direction.
- Make sure that all other electrical contacts are working. To check them, you can bridge the conductors with a strip of kitchen foil that is held in place with clothes-pegs.
- Moist air will increase corona discharge. Wait till the air is dry enough.
- If you move the machine from the cold to the warm, moisture will condensate on the machine. This will discharge the Leyden jars and inhibit sparks. Wait till the machine is warm and dry.
- Sometimes the machine needs to discharge itself completely. After a short break it should work again as normal.

2. What can I do with my Wimshurst Machine?
- Most impressive are of course the bright, crackling spark discharges. These are like tiny flashes of lightning: Normally air is a non-conductor, but when the voltage between the spheres (or the clouds) has become high enough, the air is ionised in a thin channel between the electrodes. This channel can conduct electricity and the collected voltage rapidly discharges through the channel: lightning!
- There are a lot of famous experiments involving static electricity for which your Wimshurst Machine is ideal, e.g. the electroscope, the electrostatic pendulum, the detection of ion wind with a candle flame, or the electrostatic motor, which is driven by point discharges.
- We will publish from time to time on our AstroMedia Web Shop instructions for experiments that you can do with your machine, so check it. You can also find a lot of ideas on YouTube.

3. Is the high voltage of the Wimshurst Machine really harmless?
Yes! It is not the voltage that is crucial, but the energy of the discharge , which is determined by the electrical current and its duration. According to the International Electro Technical Commission document IEC 479-2:1987, a transient or capacitive discharge, as is the case with static electricity, requires energy in excess of 5000 mJ (millijoule) to produce a serious risk to health. The German Federal Institute for Occupational Safety and Health states that a discharge is safe, if the energy doesn't exceed 350 mJ. Our Wimshurst Machine can only produce a maximum discharge energy of 49 mJ and usually the value is much lower. Nevertheless keep in mind that even a harmless electric shock can still be unpleasant.

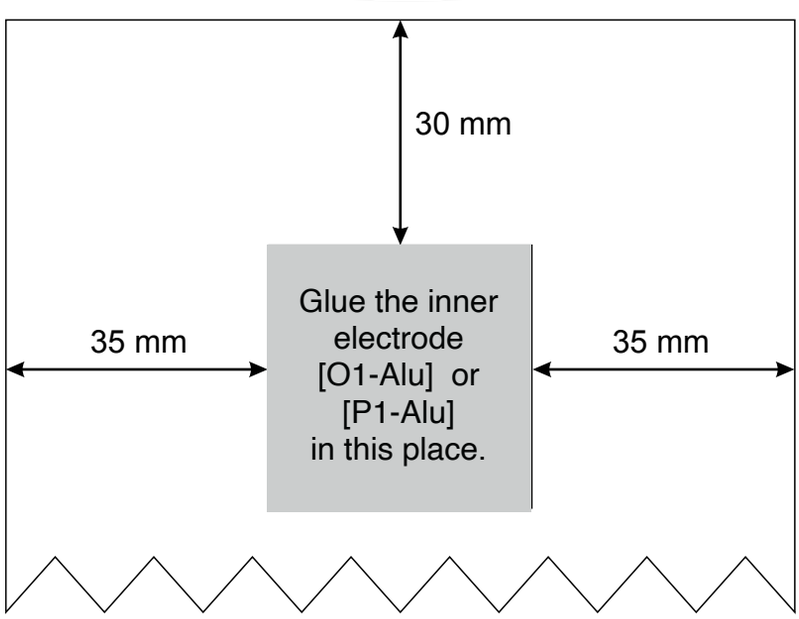
4. I have more ideas for experiments. Can I send them to you?
Definitely! Go to our website and search for our last contact email adress. We are looking forward to your comments, ideas, videos, drawings, etc and will publish them on our website.





Segment discs:

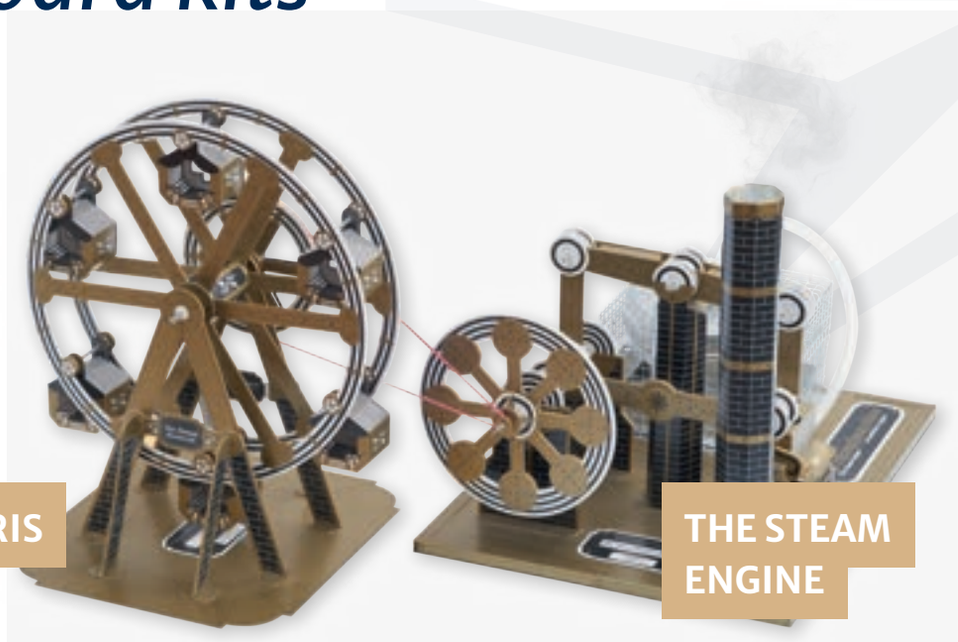
Glueing pattern for the aluminium segments [H1-Alu to H24-Alu] and [H25-Alu to [H48-Alu], respectively.



Leyden jars:

Glueing pattern for the inner electrodes [O1-Alu] and [P1-Alu] on the PVC film of the Leyden jars.

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