Solar System Orrery (3D printed)

by **dragonator** on July 4, 2016

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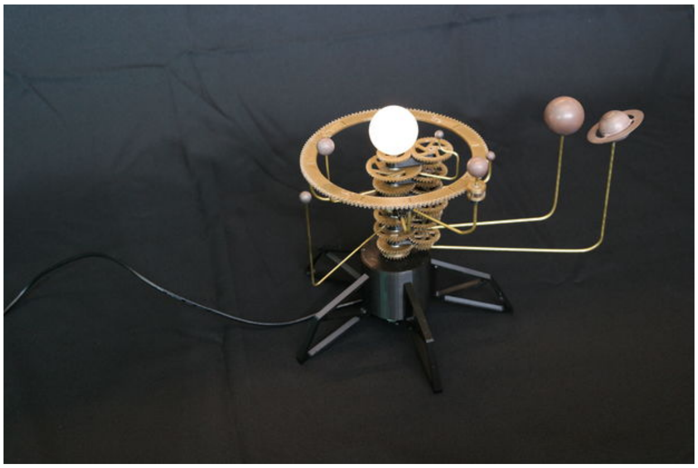
Intro: Solar System Orrery (3D printed)

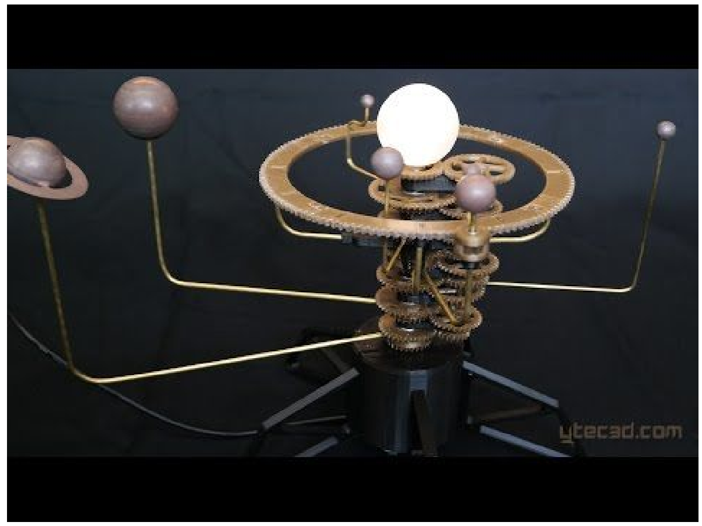
"An orrery is a mechanical model of the solar system that illustrates or predicts the relative positions and motions of the planets and moons, usually according to the heliocentric model." -Wikipedia-

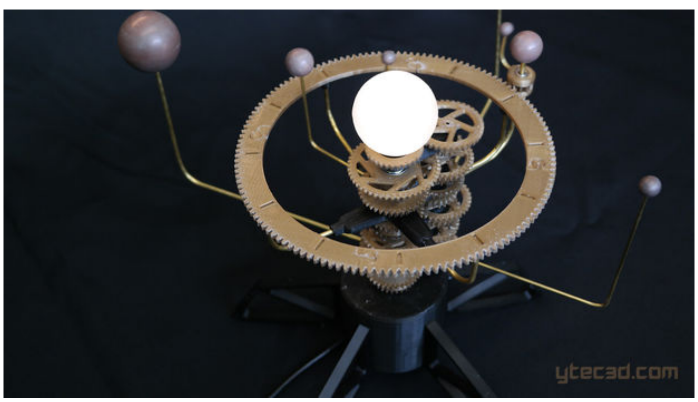
In this Instructable I will share how to make a fully 3D printed orrery of the sun, with the planets from Mercury to Saturn. The earth has a moon orbiting around it. The orrery is a combination of 3D printed parts, brass tube and miniature bearings. Optionally, the planets Uranus and Neptune are also designed, but it makes the orrery quite large and both planets hardly move. I personally don't think it is wise to make one with the last 2 planets. Most old orreries don't have them.

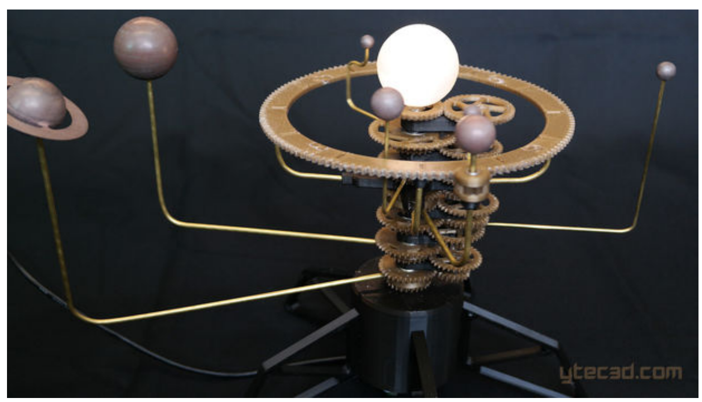
Optionally, using a slipring and leds, the sun can be made to light up.

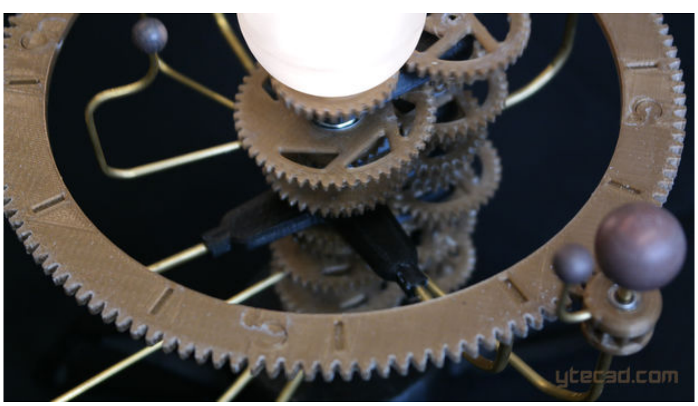
A small **Warning** about this project. While it is not impossible to make this orrery, it is a fairly advanced project. It requires an accurate printer and knowledge about using it. Having said that, I did my best to make it as simple as possible. If you are not completely sure about your skill you can make this orrery without the moon and moon ring. This is by far the most complicated part and while it will look slightly less cool, it make the project an order of magnitude simpler.

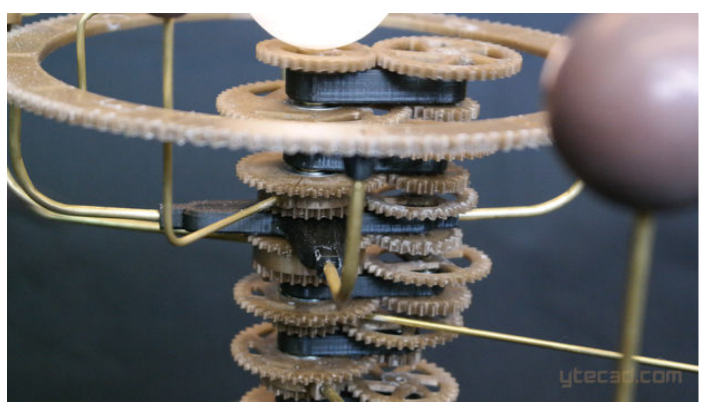


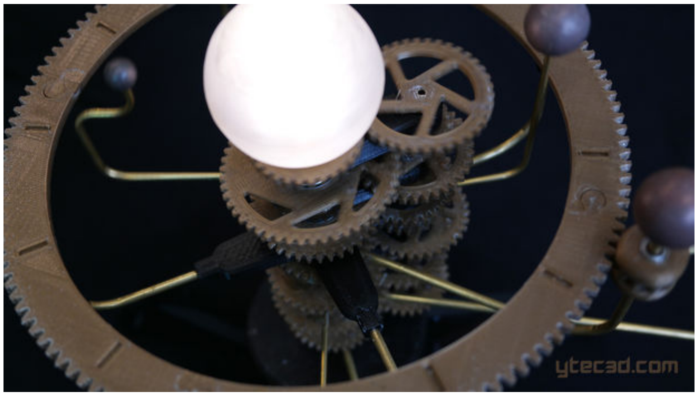


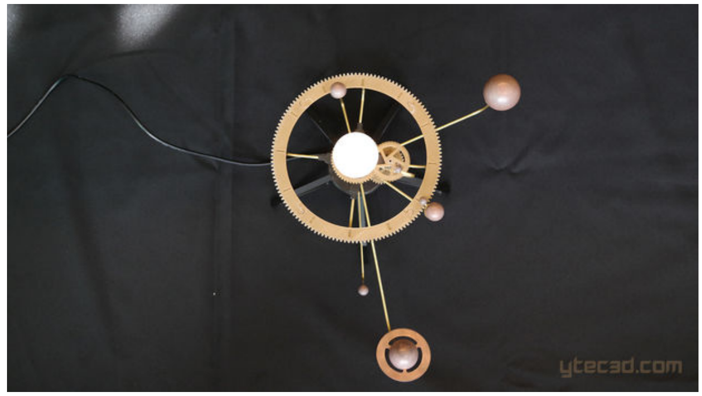


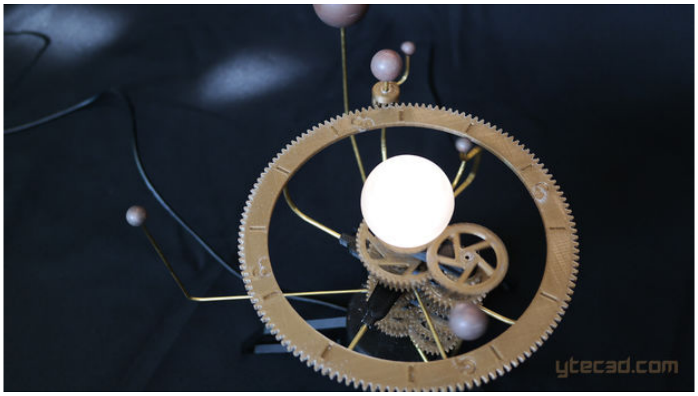












Step 1: Design process

The orrery was designed in Solidworks. Before design however, I needed to figure out all of the gears. My original goals was to make an orrery that was as accurate as I can make it. Every planet is mounted to the central shaft. This means to sets of gears between every planet. One going away from the shaft, and one going back to it. An even set of gears means that the direction of rotation is the same for every planet.

There is a catch however. In order to get back to the central shaft after each set, the sum of the top gears and the bottom gears must be the same. If this is not the case, the gears will not have the same hub to hub distance and will not line up. In order to properly calculate the ratios with this added challenge, I made an excel sheet with all possible ratios from 10 to 40 with 2 sets of gears. I simply enter the ratio, and the sheet lights up all of the gears that will product something close to that ratio.

Accuracy of the gear ratios

The next bit is a bit technical. It tells a bit about how accurate the orrery is relative to the real solar system and what gear ratios were used. This was a good part of the design process, so I wanted to include it in this Instructable.

The orrery starts at the sun. The sun rotates differently depending on where you measure, because it is plasma, not a solid. On the poles it spins every 34.4 days, on the equator it spins every 25.05. The orrery was designed with the sun making 1 revolution being 25 days.

Mercury has an orbital period of 87,9691 days. A ratio of 1:3,5187 is required relative to the sun. The gears 30:38 and 18:50 were used to create a ratio of 1:3,5185. This has an accuracy of 99,993%.

Venus has an orbital period of 224,701 days. A ratio of 1:2,5534 is required relative to mercury, and 1:8,9851 relative to the sun. The ratios 22:39 and 25:36 are used, giving a total ratio of 1:2,5527. The accuracy to the sun is 99,963%.

Earth has an orbital period of 365,256 days. A ratio of 1:1,6260 is required relative to Venus, and 1:14,61 relative to the sun. The ratios 27:31 and 24:34 are used, giving a total ratio of 1:1,6265. The accuracy to the sun is 99,995%.

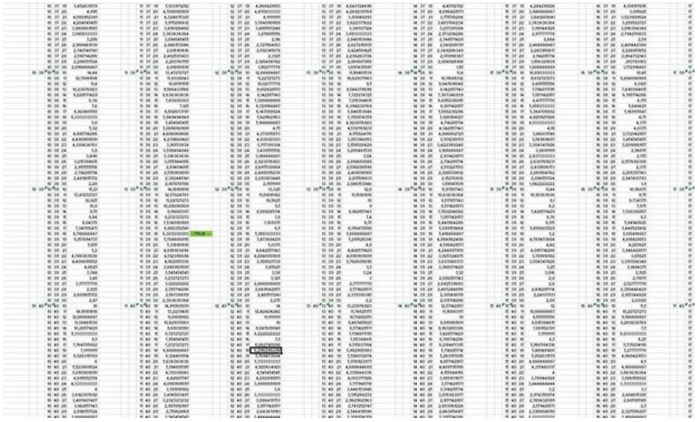
Mars has an orbital period of 686,971 days. A ratio of 1:1,881 is required relative to Earth, and 1:27,481 relative to the sun. The ratios 29:35 and 25:39 are used, giving a total ratio of 1:1,8828. The accuracy to the sun is 99,911%.

Jupiter has an orbital period of 4332,59 days. A ratio of 1:6,3051 is required relative to Mars, and 1:173,27 relative to the sun. The ratios 12:40 and 18:34 are used, giving a total ratio of 1:6,2963. The accuracy to the sun is 99,948%.

Saturn has an orbital period of 10759,22 days. A ratio of 1:2,48398 is required relative to Jupiter, and 1:430,41 relative to the sun. The ratios 19:35 and 23:31 are used, giving a total ratio of 1:2,4828. The accuracy to the sun is 99,902%.

The moon spins relative to the earth. Every rotation of the earth is 365,256 days. The moon has an orbital period of 27,322 days. A ratio of 13,3685:1 is required relative to earth. The ratio used is 136:11 is used, giving 12,3636:1. This might seem like I messed up, but this is what makes spinning gears so difficult. When the earth spins around the sun once, the moon now makes 12,3636 revolutions relative to the earth. But the earth also makes one revolution which is added to the rotation of the moon. The total is 13.3636. The accuracy to the earth is 99,963%.

The further you get from the sun, the more difficult it is to keep accurate. This orrery stays well within **0.1%** accuracy on all planets and the moon. This is more than accurate enough for me. I hope no one disagrees with me on this.



Step 2: Gathering materials

All materials mentioned are for an orrery up to Saturn. I have not done much checking for the parts for Uranus and Neptune.

Materials needed:

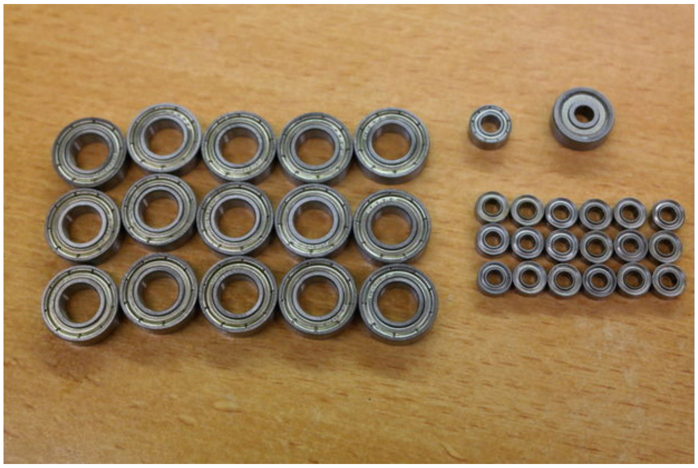
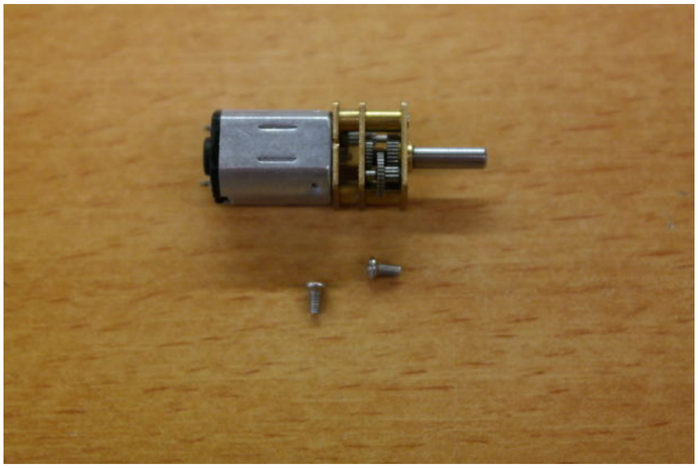
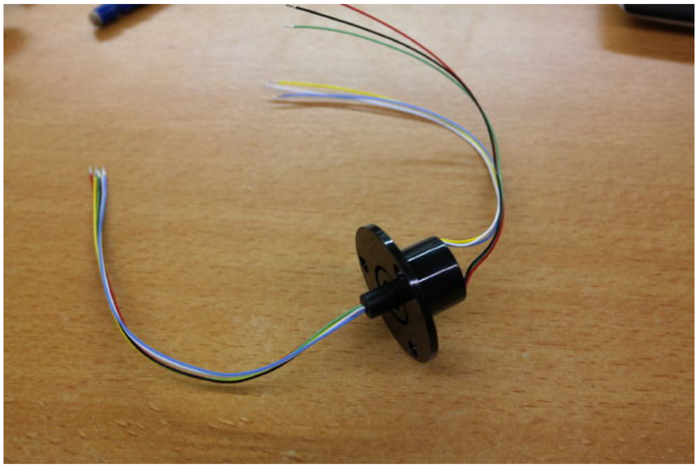
- 3D printing filament, various colors, roughly 250g;
- (11x) 688ZZ bearing; [link]
- (14x) 683ZZ bearing; [link]
- (1x) 684ZZ bearing [link]
- (1x) 624ZZ bearing; [link]
- (2x) M3x10mm screw;
- (2x 305mm) Brass tube 2mm OD;
- (4x 305mm) Brass tube 3mm OD;
- (1x 305mm) Brass tube 4mm OD;
- (1x 305mm) Brass tube 8mm OD;
- 12mm 5V Electric gear motor (100rpm is used in this project); [link]
- USB cable.

Optional materials:

- (1x) Slip ring; [link]
- (5x) 5mm Leds;
- (1x) 100ohm resistor;
- Thin electrical wire.

Tools:

- 3D printer;
- Soldering iron;
- Cordless drill (or corded, or drill press);
- Pliers;
- Drills;
- Files;
- Craft knife;
- (Hot glue is handy);
- Super glue.


Step 3: 3D printing

As suggested earlier, most of the orrery is 3D printed. All parts in the orrery are designed to be supportless and all parts are oriented the way they should be printed. The parts do have bridges and 60 degree overhangs, but most of these are very manageable. Most of the parts can be 3D printed with any nozzle, but all of the gears should be printed with a 0.3mm nozzle or smaller to get the best results.

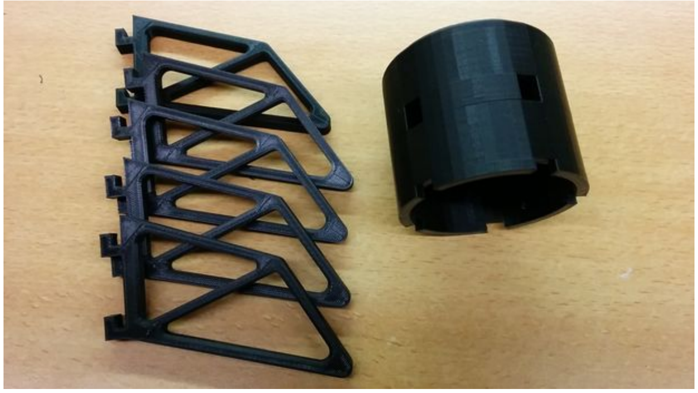
Material should not be an issue to 3D print the parts. All materials should work equally well. As for color you can pick anything. I myself prefer black and gold. For the frame I used black Colorfabb PLA. For the gears I used Real Gold PLA (real is the brand). For the sun I used Real clear PLA and the planets were printed in Bronzefill by Colorfabb. I did not track the filament use, but it should be around 250g. All in all the parts took around 12 hours of printing on my Ultimaker with a 0.3mm nozzle and 0.2mm layer height.

All gears and gear arms are marked with dots. 1 dot is the set of gears closest to the sun. From there, it goes to 6 until Saturn (and to 8 for neptune).

The 6 gear arms can be used to adjust the spacing between the gears. When I printed them at 100%, the gears were jamming, but after increasing the gear arms to 101%, the gears were tracking properly. Every 1% should give around 0.3-0.5mm of extra clearance, so not much is needed.

You can download the files here:

http://ytec3d.com/orrery

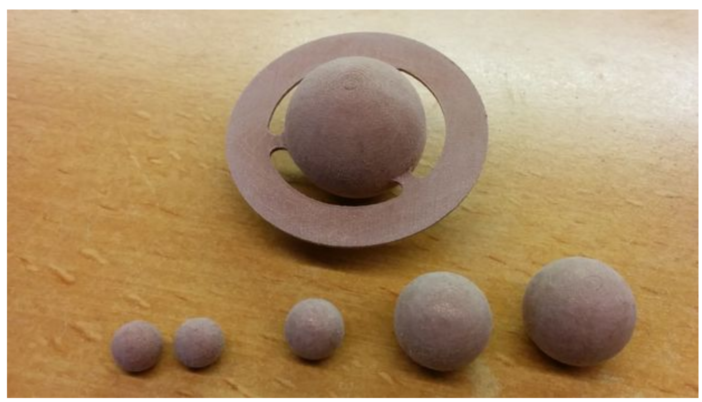



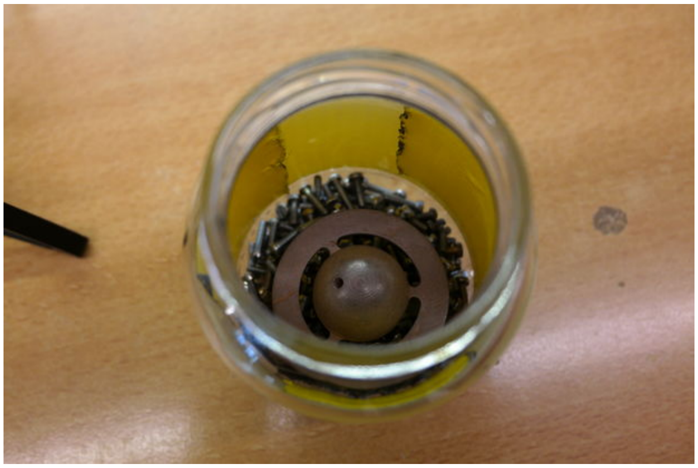
Step 4: Optional, Polishing Bronzefill

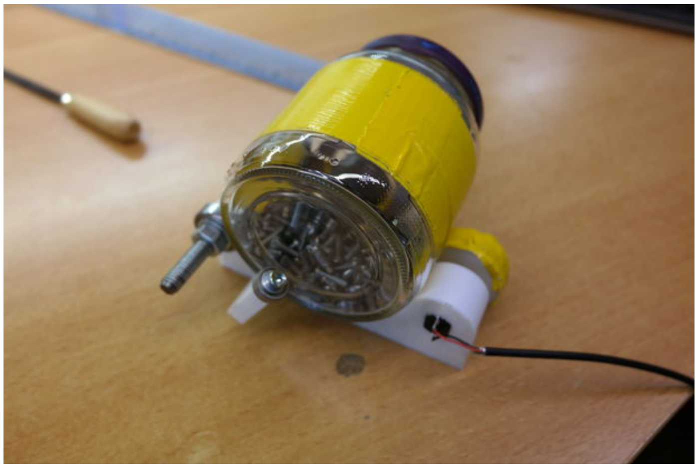
I wanted something special for the planets. I have neither the time nor the skill to 3D print all the planets and make them look like they do for real. However, I do have Bronzefill. Bronzefill is made by Colorfabb. It is a brittle PLA that is filled with bronze powder. It prints absolutely amazing and can be polished to a metal sheen.

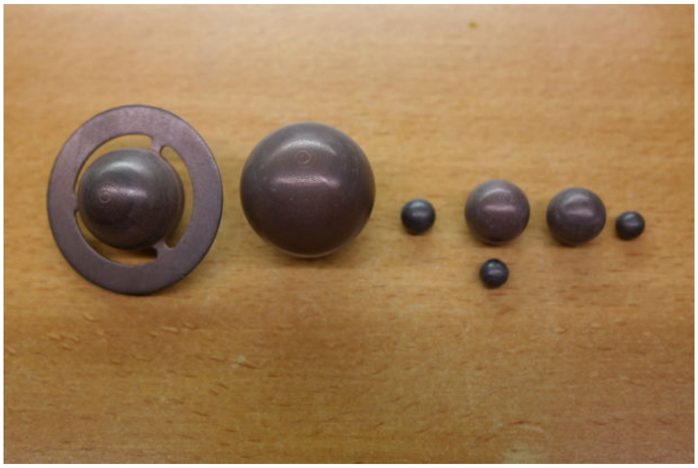
However, getting it to a metal sheen is quite a bit of work. There is a more detailed guide here, but I can give a summary.

First the surface needs to be smooth. Because Bronzefill is soft and brittle, it can be sanded smooth with little effort using sandpaper from 180 grit to 400 grit. Then steel wool can be used to get some of the metal powder to the surface. After this there are 2 options. Either use a polishing compound to get the metal sheen, or use a rock tumbler. I made a simple rock tumbler filled with M3 steel screws to polish the planets. Depending on the size, it takes between 2 and 8 hours of polishing.







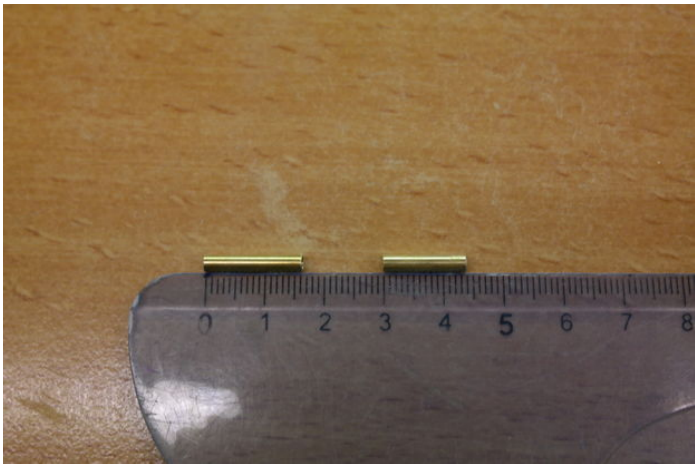


Step 5: Cleaning The 3D Prints and preparing the Parts

While the prints will probably come of the printer in a decent state, most of the parts will require a bit more work before they can be used. Most of this work for me was removing some small strings and boring out the holes for the axles and bearings. There are a few drill dimensions required here: 2, 3, 4, 7, 8 and 9mm. If you have a drill press available use that. Else take great care to drill the holes perpendicular. I only had a cordless drill and some of the gears are wobbling.

- 2mm drills are only needed for some of the arms that hold the planets and the moon;
- 3mm drills are used for Earth, Jupiter, Saturn, the moon ring and all shafts for the planet gears;
- 4mm is used for the shaft that runs to the sun and the respective gears;
- 7mm is used for the gear arm bearing holes. The 3x7x3mm bearings will fit in here;
- 8mm is used for anything that fits on the central orrery shaft.
- 9mm is used for the gear arm with 1 dot, halfway to support the 4x9x4mm bearing.Do not go completely through the arm.
- The big 688ZZ bearings can be reamed with a file should the hole be too tight.

The bearings can be press fitted into the plastic using a vice. Be careful here. The bearings should have a tight'ish fit, but you should not have to force it. If the bearings are really tight, ream the holes a bit more. Especially PLA is fairly brittle and will break before it will bend.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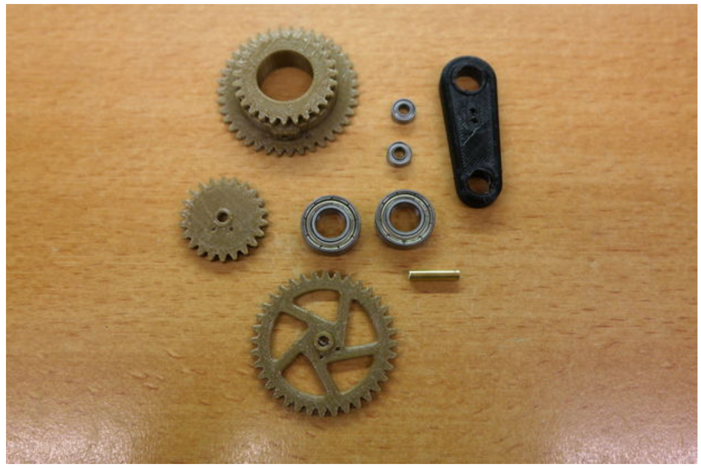
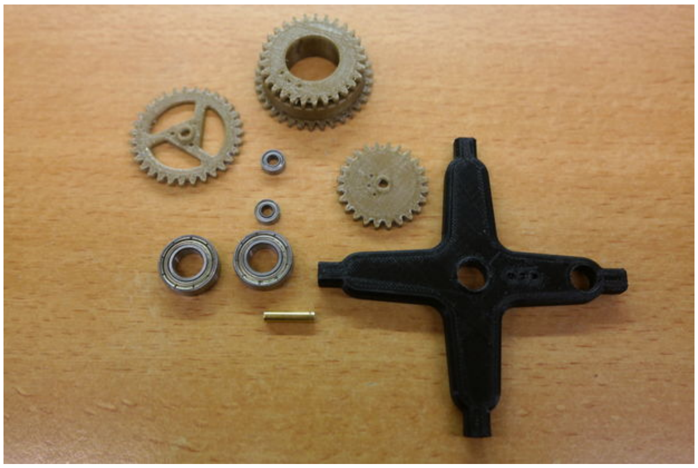
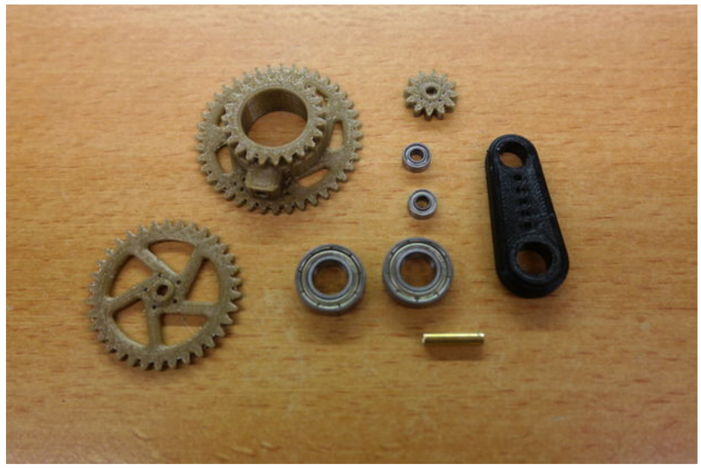
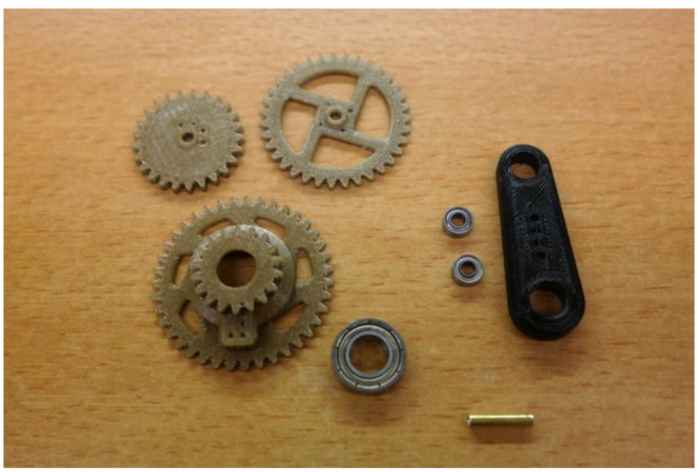
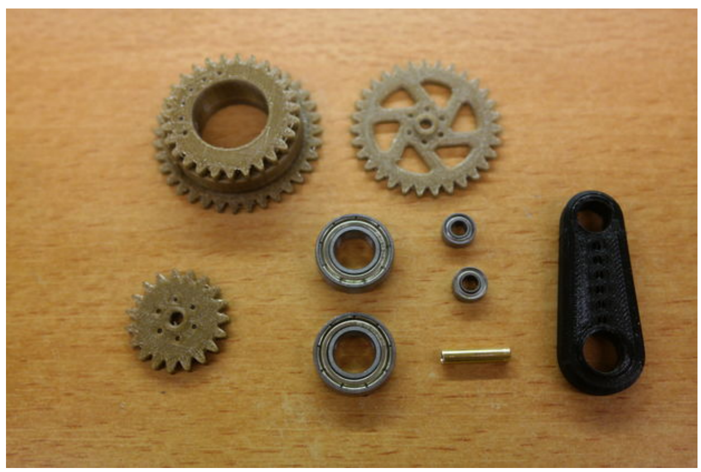
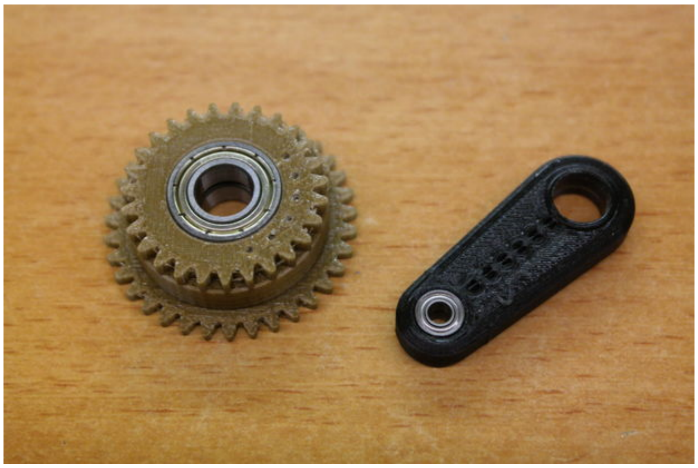






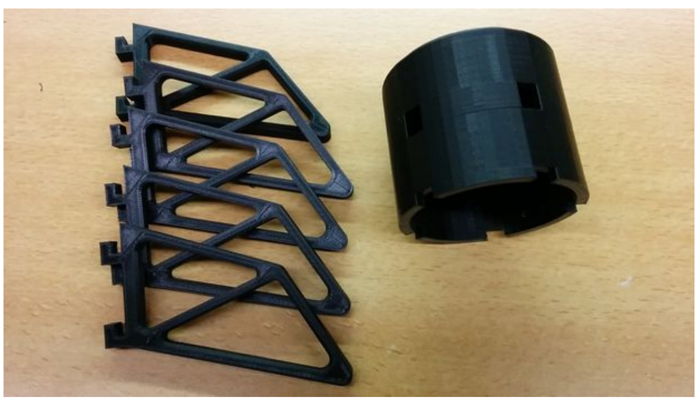


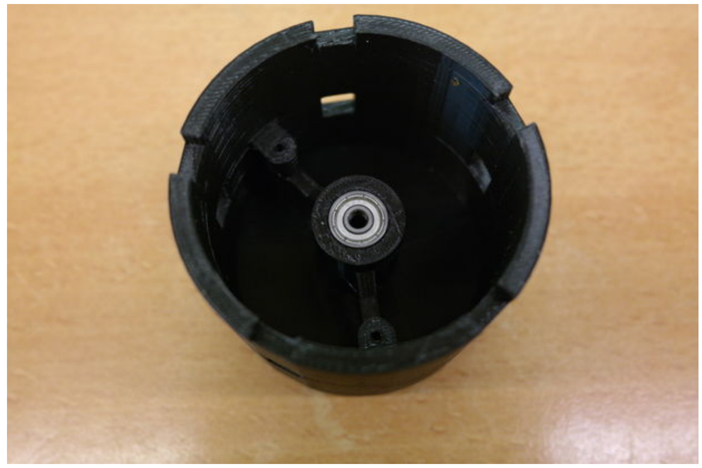




Step 6: Assembling The Base

The base is fairly straight forward. The 8mm shaft sits in the central hole. An 8mm drill can be used to ream the hole until the 8mm shaft fits. The 624ZZ bearing is placed in the bottom of the base. This is the second support bearing for the sun. The legs have tiny hooks that grab into the base. No glue or screws are required to keep the legs on the base.



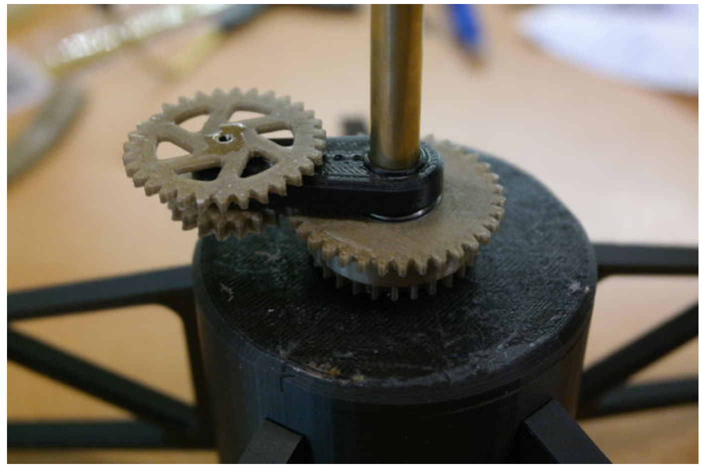
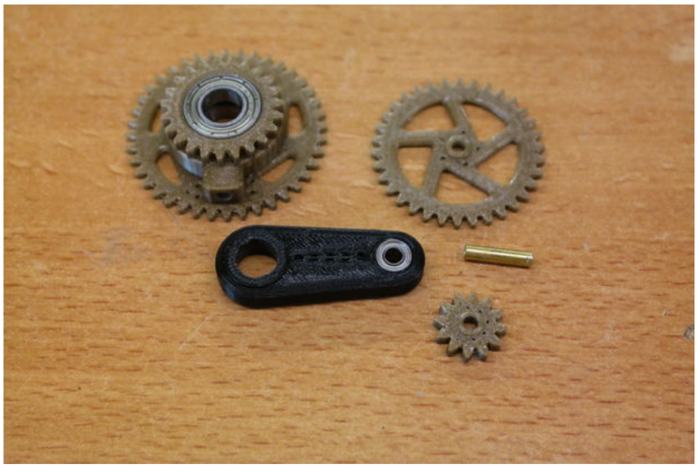


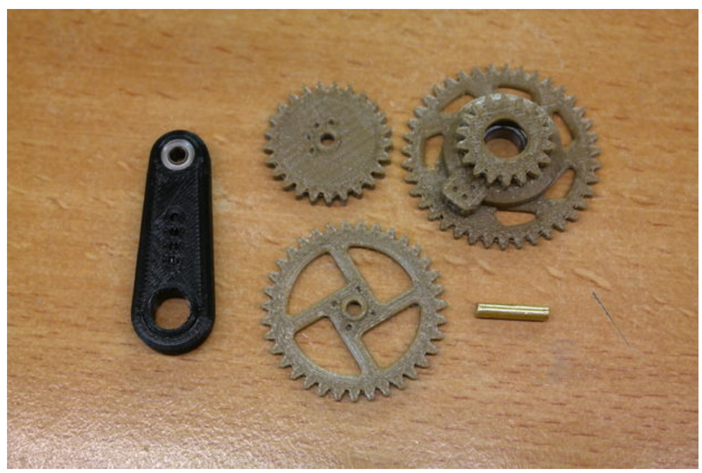
Step 7: Gears For Saturn To Mercury

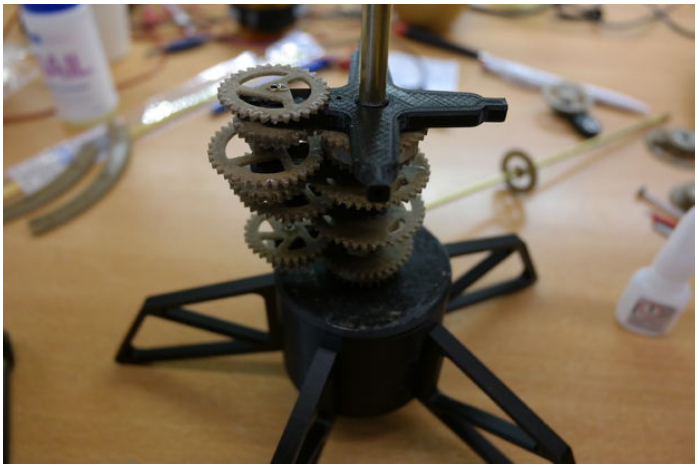
On top of the base the gears for all of the planets can be assembled. I would give a full written guide, but words have a hard time describing the proper order to stack the gears. I hope the images and the drawing will be sufficient. If they are not, ask and I will add more information. A few notes to accompany the images:

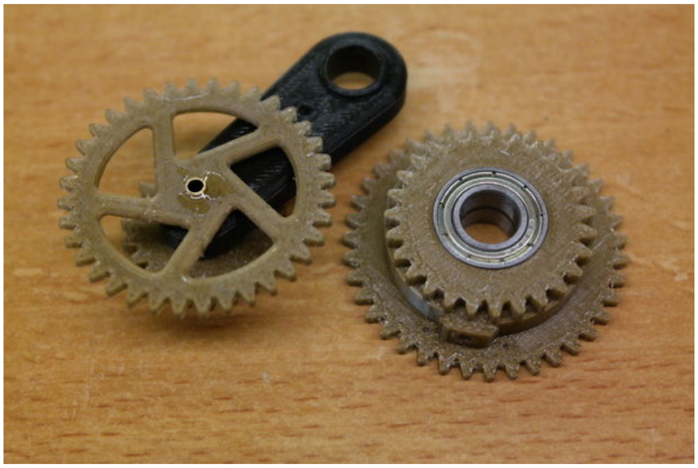
- There are dots on all gears and gear arms. These indicate their location in the orrery. 1 dot is Mercury, 2 dots Venus, 3 dots earth, 4 dots Mars, 5 dots Jupiter and 6 dots Saturn.
- The orrery is assembled from Saturn (6 dots) to Mercury (1 dot). Bottom to top.
- The smaller gears all have an edge on one side. This is the side that faces a bearing.
- The gear arms should be mounted with the dot facing up.
- The gears can be secured to the shafts with a small dot of super glue. The same glue can be used for securing the bearing in the gear arms if needed, but be very careful not to get glue in the bearing.

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	624 bearing		1
2	683 bearing		12
3	684 bearing		1
4	688 bearing		11
5	DC gear motor Ø12		1
6	Slipring		1
7	SS orrery Y10-P01-00	Base tube	1
8	SS orrery Y10-P02-00	Sun bearing holder	1
9	SS orrery Y10-P03-00	Base body	1
10	SS orrery Y10-P04-00	Base Leg	5
11	SS orrery Y10-P05-00	Motor mount	1
12	SS orrery Y10-P06-00	Motor driver gear	1
13	SS orrery Y10-P07-00	Motor driven gear	1
14	SS orrery Y20-P03-00	Sun Mercury gear 2	1
15	SS orrery Y20-P04-00	Sun Mercury gear 3	1
16	SS orrery Y20-P05-00	Sun Mercury gear 4	1
17	SS orrery Y20-P07-00	Gear arm Mercury Venus	1
18	SS orrery Y20-P08-00	Mercury Venus gear 1	1
19	SS orrery Y20-P09-00	Mercury Venus gear 2	1
20	SS orrery Y20-P10-00	Mercury Venus gear 3	1
21	SS orrery Y20-P11-00	Venus Earth gear 1	1
22	SS orrery Y20-P12-00	Gear arm Venus Earth	1
23	SS orrery Y20-P13-00	Venus Earth gear 2	1
24	SS orrery Y20-P14-00	Venus Earth gear 3	1
25	SS orrery Y20-P15-00	Gear arm Earth Mars	1
26	SS orrery Y20-P16-00	Earth Mars gear 1	1
27	SS orrery Y20-P17-00	Earth Mars gear 2	1
28	SS orrery Y20-P18-00	Earth Mars gear 3	1
29	SS orrery Y20-P19-00	Gear arm Mars Jupiter	1
30	SS orrery Y20-P20-00	Mars Jupiter gear 1	1
31	SS orrery Y20-P21-00	Mars Jupiter gear 2	1
32	SS orrery Y20-P22-00	Mars Jupiter gear 3	1
33	SS orrery Y20-P23-00	Gear arm Jupiter Saturn	1
34	SS orrery Y20-P24-00	Jupiter Saturn gear 1	1
35	SS orrery Y20-P25-00	Jupiter Saturn gear 2	1
36	SS orrery Y20-P26-00	Jupiter Saturn gear 3	1
37	SS orrery Y20-P35-00	Gear shaft 1	5
38	SS orrery Y20-P36-00	Gear shaft 2	1





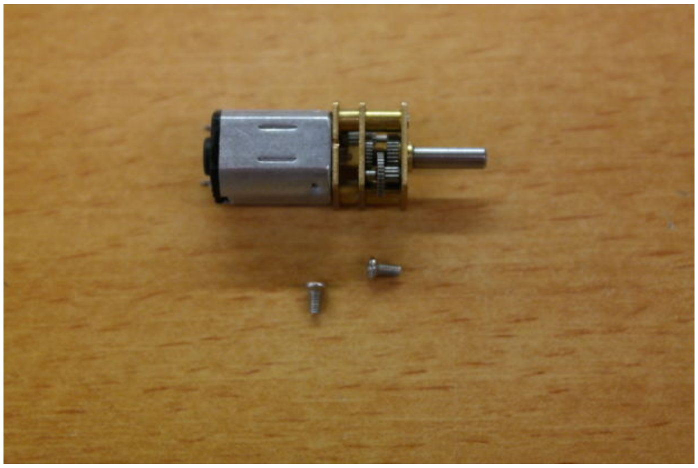
Step 8: Motorizing The Sun

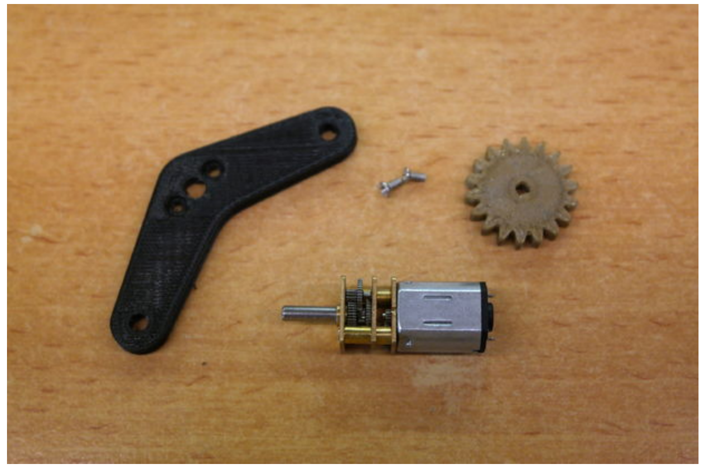
The motor will turn the orrery. The motion starts at the sun. The sun will get the same speed as the motor, so do not pick it too fast. 100 rpm gives a fairly fast orrery. 30 rpm makes it more gentle.

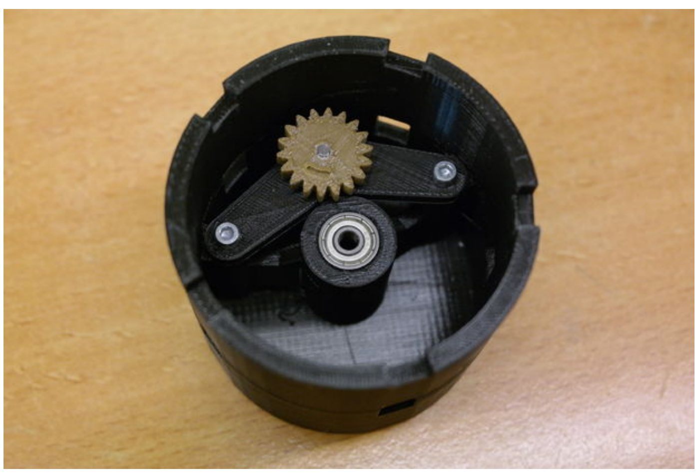
The motor should have come with 2 small screws. These can be used to screw the motor to the mount. The gear used is one of the 2 gears with a slot in stead of a dot. The gear with the D-shaped hole is the gear that needs to be mounted to the motor. Do not drill this gear. The gear is mounted on the shaft of the motor and should be a tight fit. The hole of the gear can be filed to make it fit the motor better.

Last, the motor mount can then be mounted in the base using the 2 M3x10 screws. The screws need to tap into the plastic of the base.

Wires can be soldered to the motor before mounting it in the base. A USB cable can be used to provide the power to the motor. When you cut it, you will see a red, black, white and green wire. Red carries the 5V, black is the ground. Solder these 2 wires to the motor and check if the sun spins the right way around (counterclockwise as seen from the top). If it doesn't spin the correct way, swap the ground and 5V on the motor. The other 2 wires should be protected against shorting on something, but can otherwise be ignored. If the sun is going to be lit, keep the final wiring free to add the power of the sun to the 5V





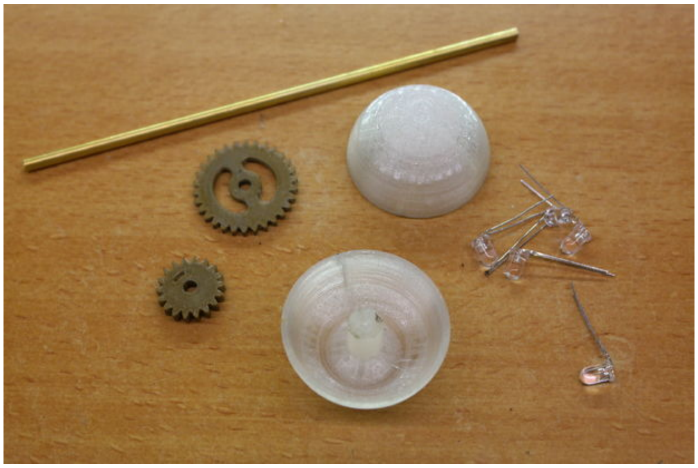
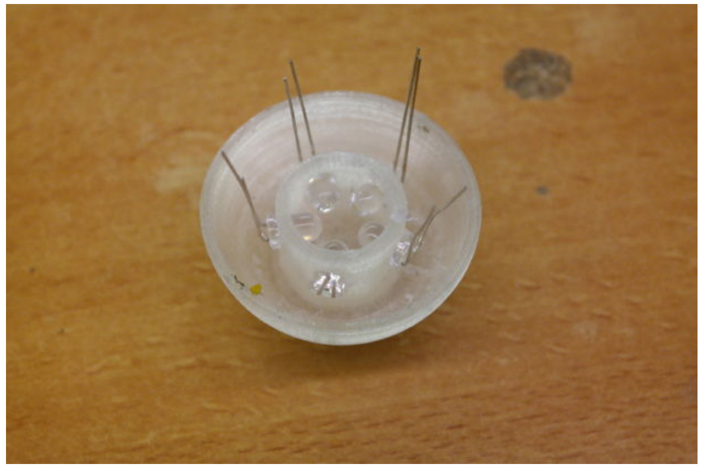
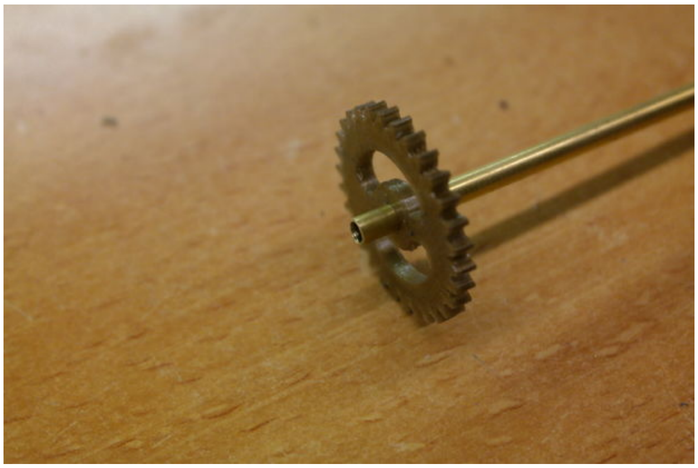
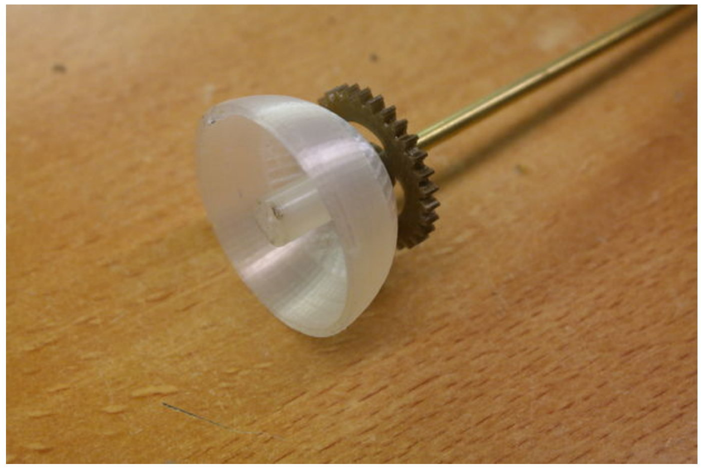
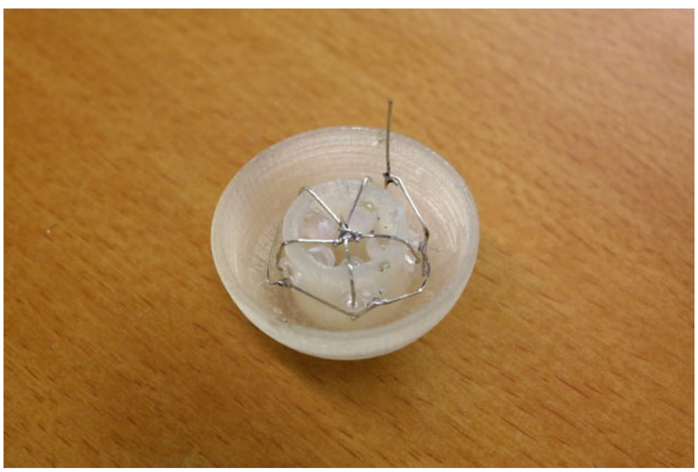
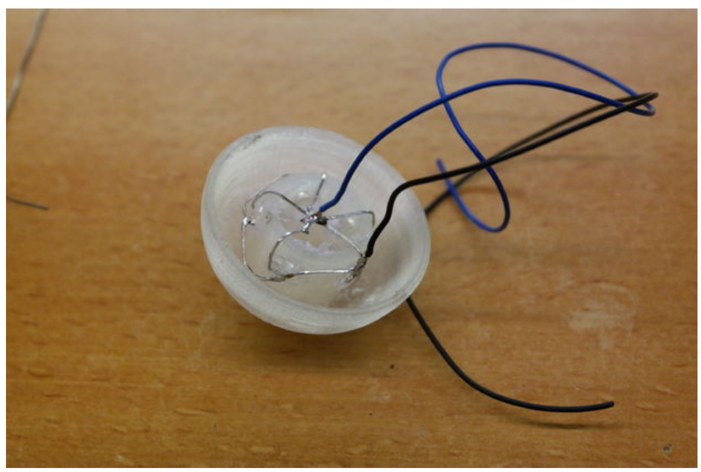


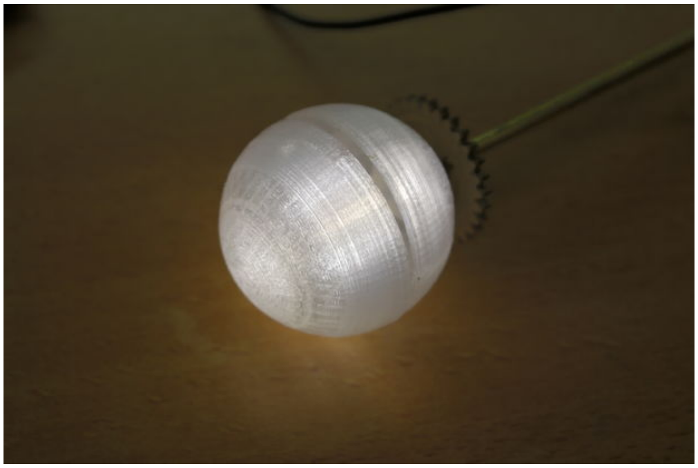
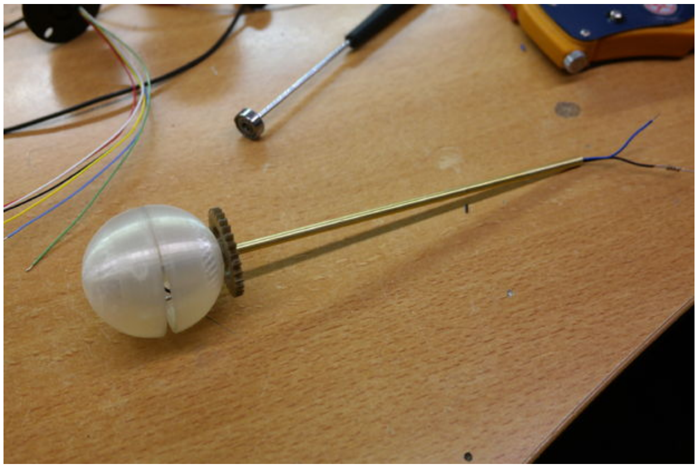
Step 9: The Sun

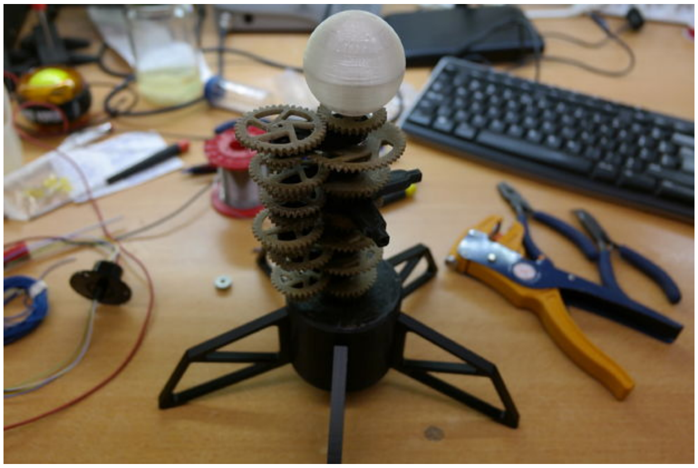
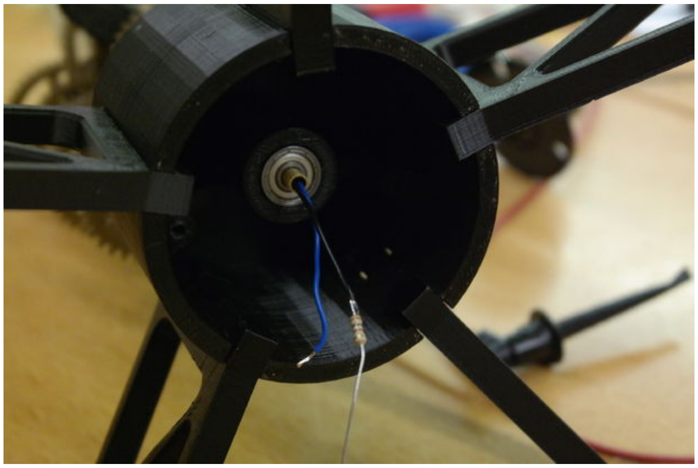
Depending on how complicated you want to make it, the sun is a very simple or somewhat complicated part. If you want an unlit sun, the sun is only needs to be mounted to the shaft, as well as the 2 spoke gear on the top of the sun and the slotted gear with the 4mm hole on the bottom in the base.

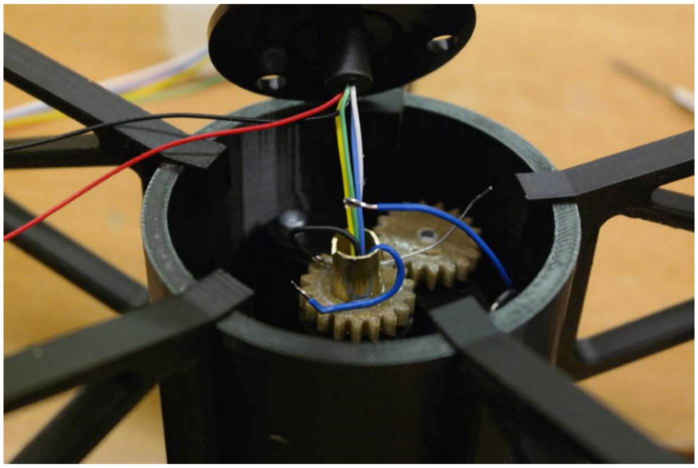
If the sun is 3D printed in clear plastic, the sun can be made to light up with 5x 5mm Led's. For scientific accuracy the sun should be made a hard white, but I settled for warm white because it is prettier. The 5 Led's are mounted in the top side of the sun, facing in. If they face out, they will create bright spots on the surface. The leds are soldered in parallel, anodes to anodes, cathodes to cathodes. A 100ohm resistor is added to the anode to limit the current. I mounted this resistor near the slip ring.

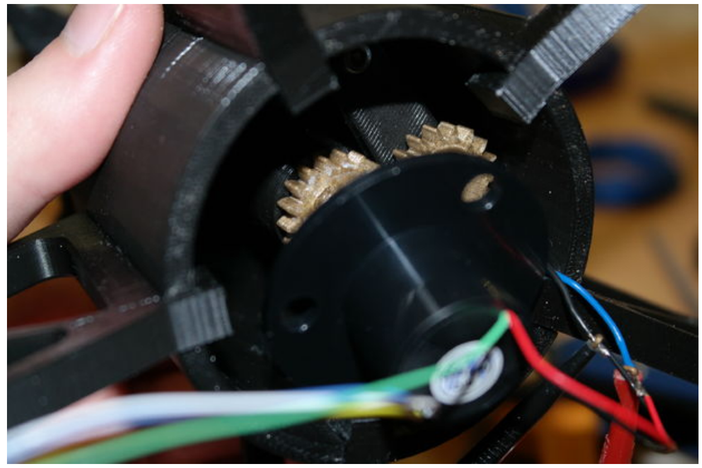
2 Wires run down the length of the 4mm tube. At the bottom is a slip ring that allows these wires to spin with the sun while maintaining electrical contact. I left space for said slip ring in the base, but an exact mounting mechanism is not provided. I bodged my slip ring to the bottom of the base with some spare pieces of brass tube. The power to the Led's is attached to the same power as the motor, the 5V from the USB cable.

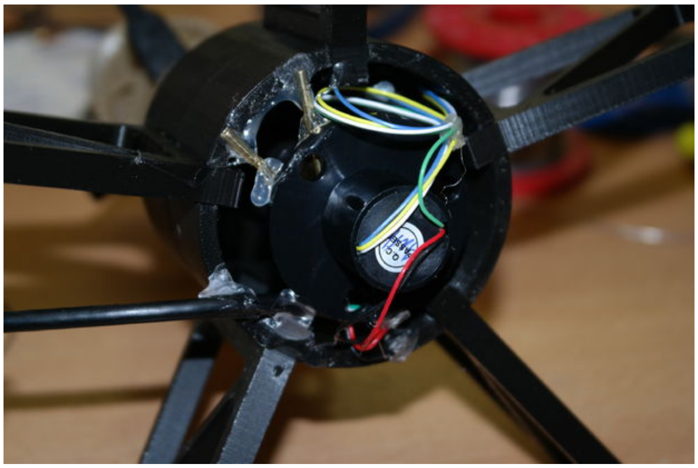







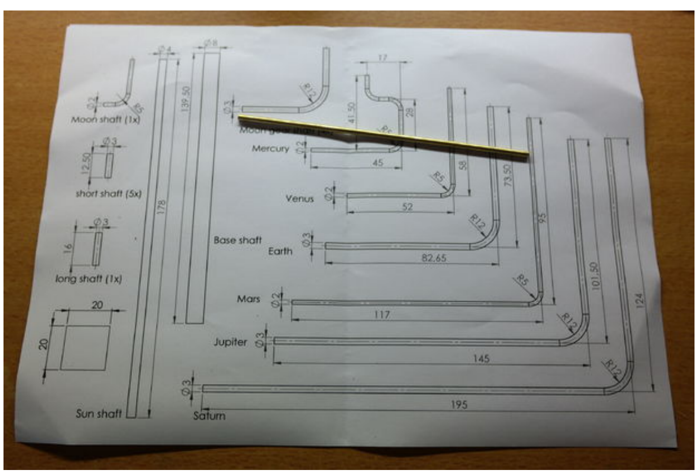


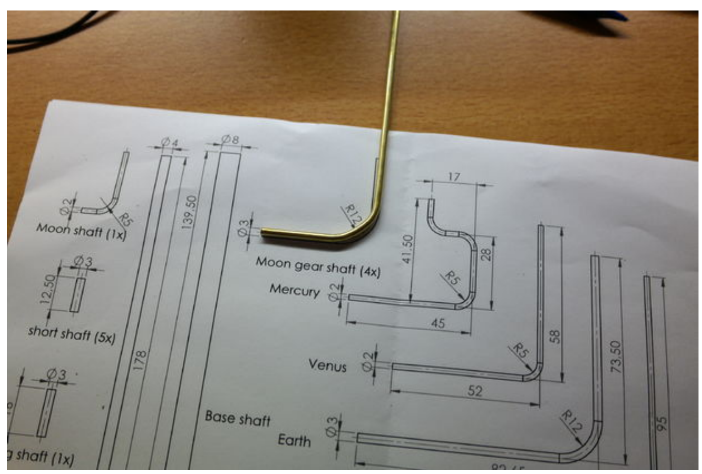


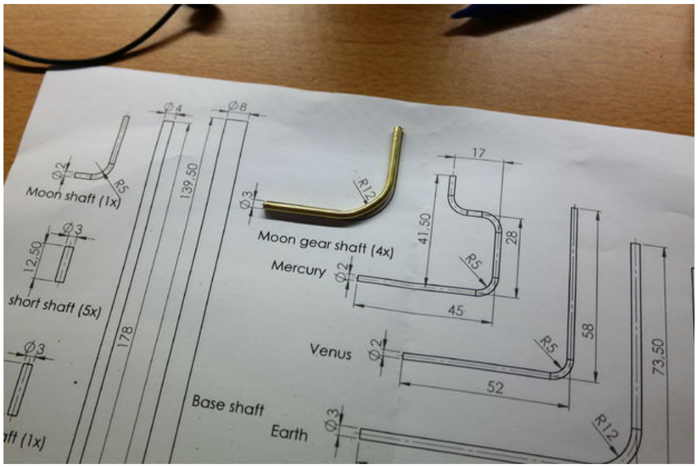
Step 10: Bending Pipes

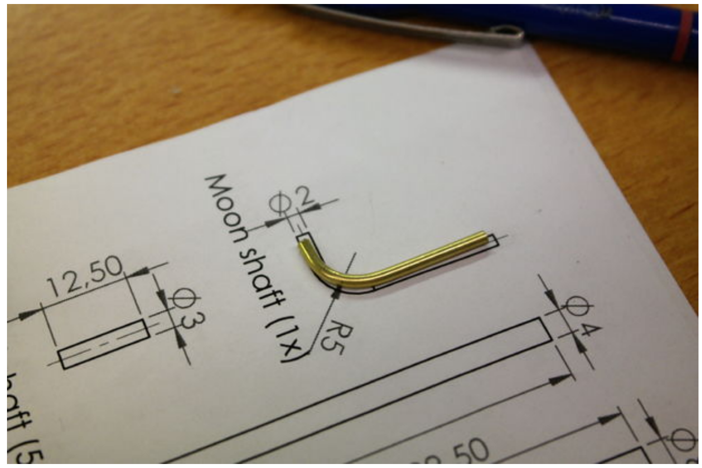
The orrery requires a few pipes to be bent. For this I made a template. The template has all the tubes for the orrery up to Saturn. The template can be printed on A4 at 100% scale. For tubes I got 305mm long pieces of brass tube with a wall thickness of 0.45mm at a model train shop. The only tubes that require bending are 2mm and 3mm. These can be bent by hand or using pliers. The template is a guide. A difference of 1mm is not a disaster.The 20x20 is used as a reference and should measure 20mm by 20mm.

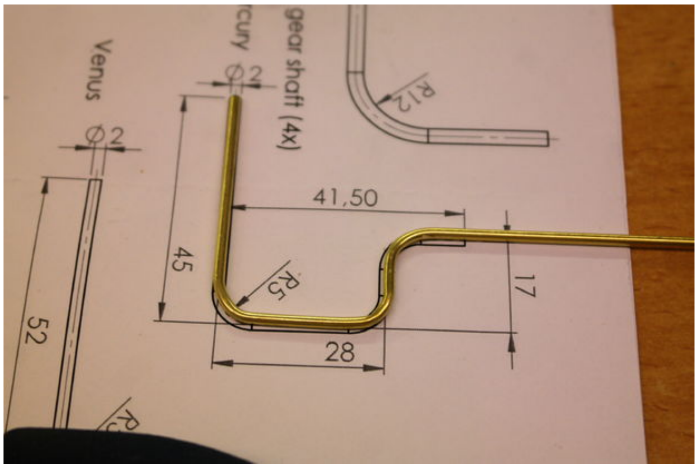
The tube for Saturn can be bent from a full piece of 305mm brass tube, but only just. Work your way from the longer to the shorter pieces to use the least amount of material.







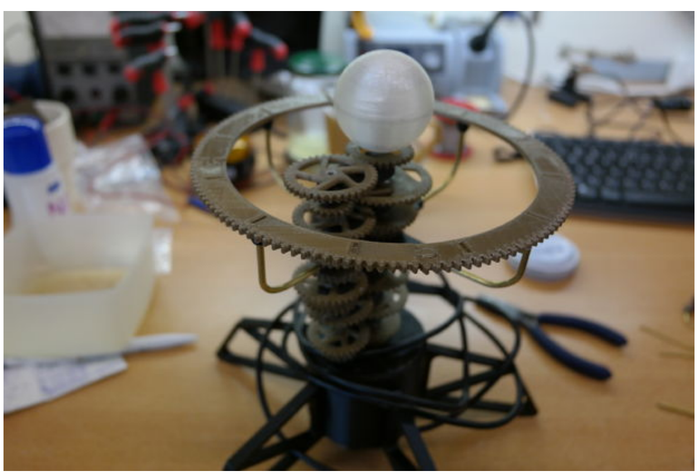


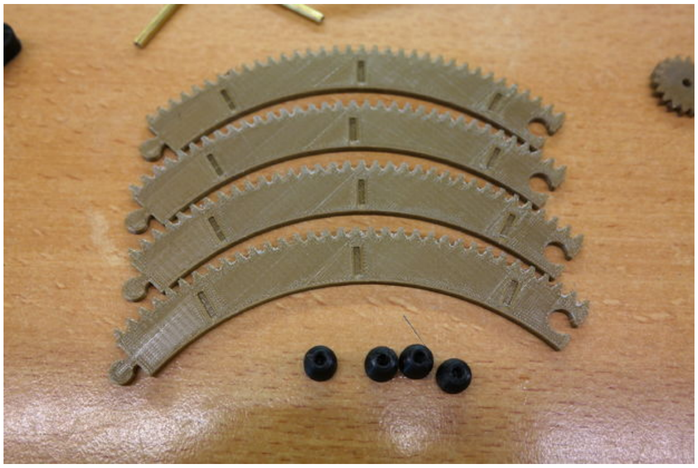


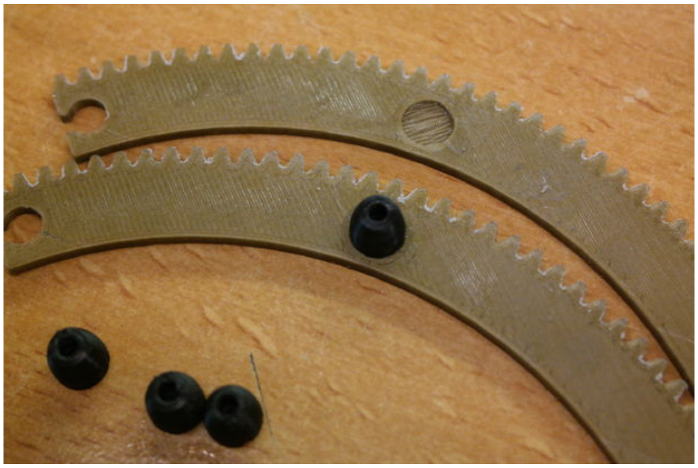
Step 11: Moon ring assembly

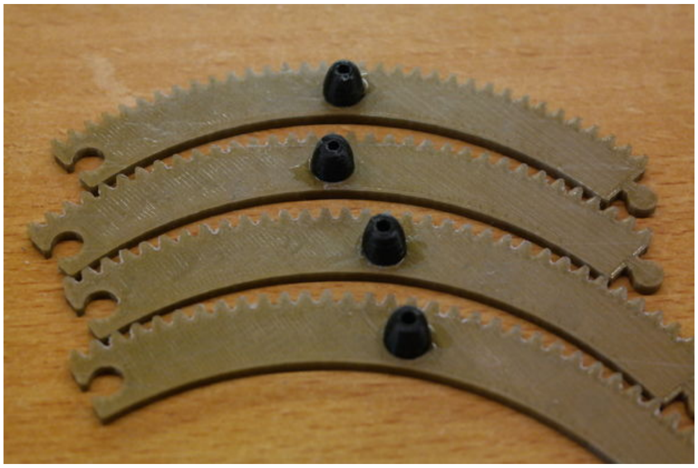
The moon ring is the most difficult part of the orrery. Assembly is fairly straight forward, but it needs to be dead in the middle of the orrery. First the ring itself needs to be assembled. The 4 ring pieces have holes on the bottom where the the 4 small carriers can be glued into. The ring itself simply snaps together. The short side of the moon gear arm needs to be mounted in the ring.

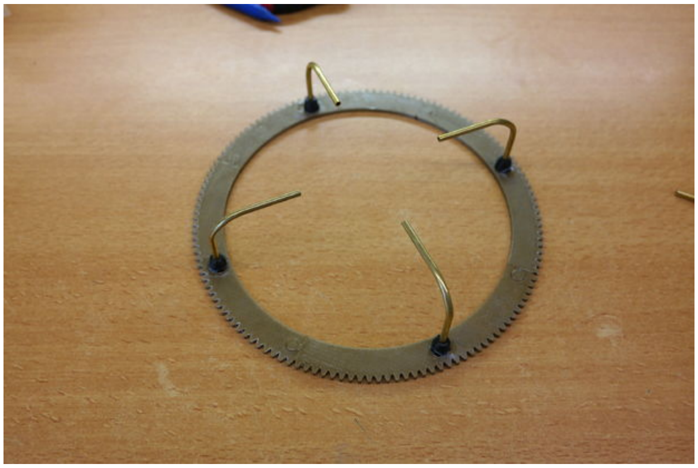
The ring can now be placed on the orrery and adjusted. The goal here is to center the ring gear. This can be done by mounting the earth with the moon to the orrery and spinning it. When the earth moves around, the distance between the gears of the moon should remain equal, both sideways and vertical. This can be done by sliding in and out the arms of the moon gear ring. Once the moon tracks properly on the gear, the moon ring gear can be secured with super glue. Be warned that this step is quite complicated and takes some time. It took me over an hour and some extra drilling in gear arms to get it to track.

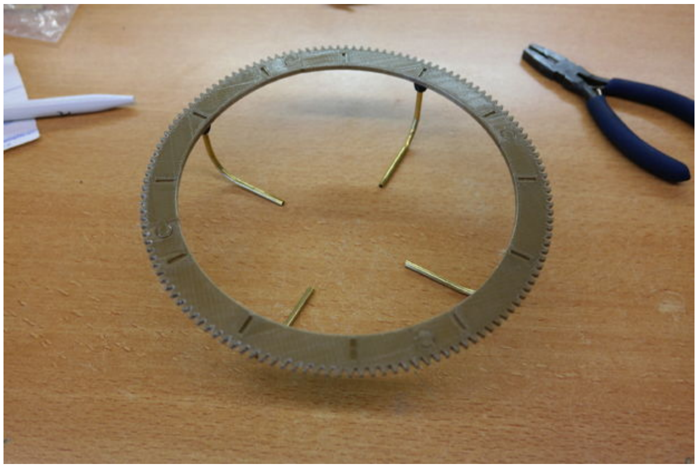










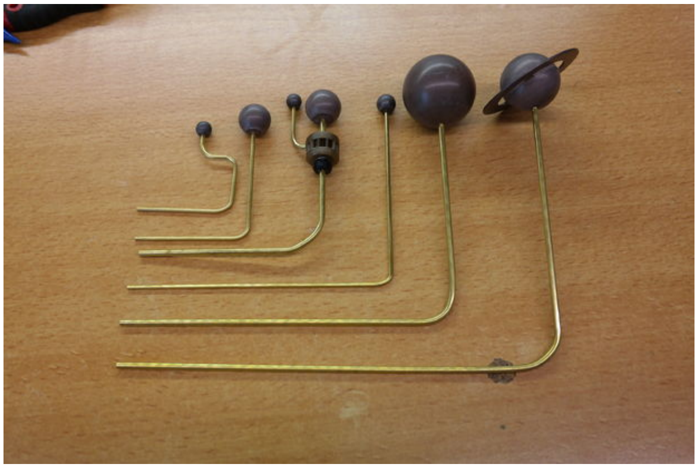


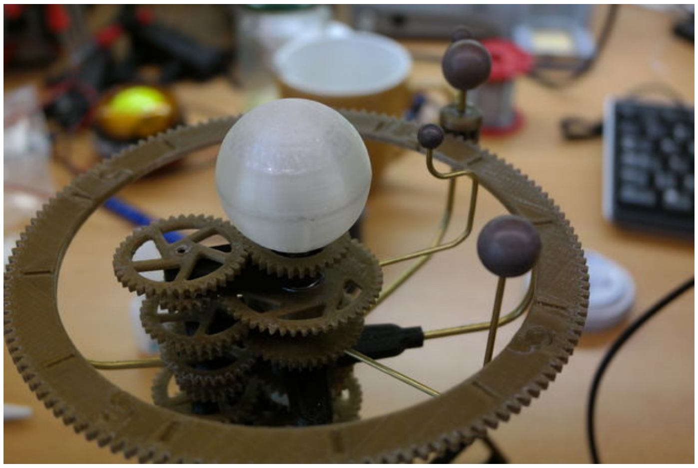
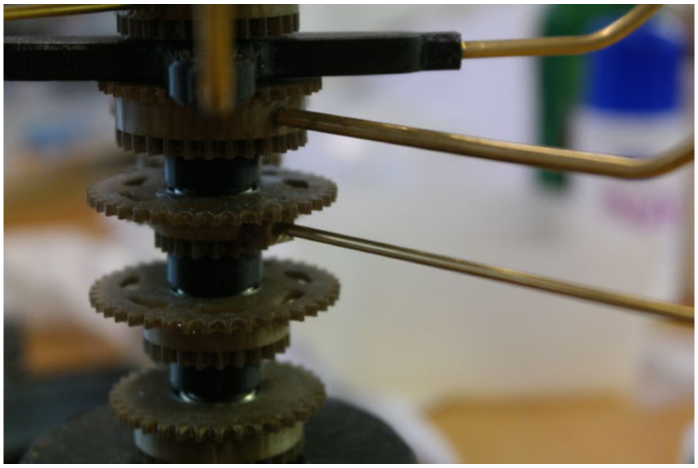
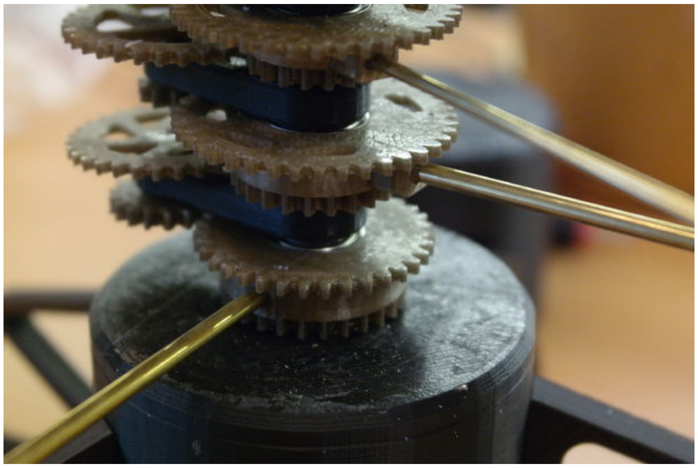
Step 12: Mounting The Planets

With everything else assembled, the planets can be put in place. A few helpful notes:

- From small to large, the balls are: Mercury, the Moon (both the same size), Mars, Venus, Earth, Saturn (with the ring) and Jupiter.
- The planets are mounted: Mercury, Venus, Earth with moon, Mars, Jupiter and Saturn. If you needed this note to remember the proper order, shame on you.
- Mercury, the Moon, Venus and mars have 2mm shafts. Earth, Jupiter and Saturn have 3mm shafts.
- The shafts can be secured in their gears using a small drop of super glue.
- In the previous step the moon ring and the earth should have been aligned. All other planets should have clearance.
- If the planets do not have the clearance to move past one-another, the arms can be slightly bent.

There is not much else to this step.



Step 13: Appreciate it

Now enjoy a finished orrery. All in all I think the orrery came out really well. Apart from the moon it was really easy to assemble and the printing time was less than I initially expected. I think that without the moon ring this would be a nice project for someone who got the basics of 3D printing and now wants something really cool to make. I will keep mine on display somewhere on my bookshelf. With the USB, I can easily power it every now and then without worrying about damaging it.

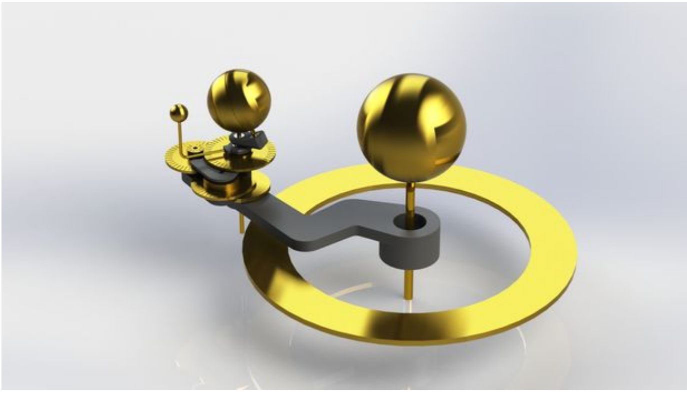
Now for some future ideas. Obviously I could make an orrery with ALL the planets and ALL the moons, spinning. Maybe add Ceres, Pluto, the asteroid belt. But while some of those things might actually be cool, others will be overly complicated for no apparent reason. There is one thing though, and the image above gives it away.

This project is an orrery, but originally, this was planned to be a Tellurion, or a Sun-Earth-Moon orrery. A Tellurion is an orrery with only the sun, the earth and the moon, but way more accurate than they are portrayed in my orrery.
The sun spins, the earth spins around the sun, the earth rotates with the tilt it has for real. The moon spins around the earth the way it does for real and if you want to make it really cool, the moon's tilt shifts the way it does in the real world.

My initial idea was that with only 3 bodies the Tellurion would be simpler than the orrery. Boy was I wrong. While there are fewer bodies, their relative motions are way more complicated. The earth actually makes 366,25 rotations for every 365,25 days. The extra rotation comes from the earth also spinning around the sun. This is just one of the things to keep in mind and after a day of design, I had a headache.

So maybe some other time will I make a Tellurion to sit next to my Orrery. For now, I will enjoy my Orrery by itself.

Thanks for reading this Instructable.



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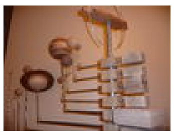

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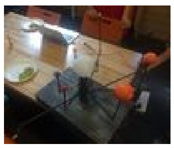

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