

# COMPACT CLOCK

## SP16 Build Notes

Assembly notes for a simple compact pendulum clock

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## Revision History

20-Mar-2026 Original version

## Description

This is a compact pendulum clock with easy construction. The parts list is as small as possible for a fully functional clock with an 8 day runtime. The compact design allows all gears to be visible from the side profile. Everything fits on just three arbors. It is my easiest clock to build.

Stacking all the gears into such a small space presented several challenges. New innovations were needed for the winding ratchet and friction clutch to make everything fit. Additional enhancements were added to simplify the design. The pendulum has been moved inside the frame to make it more efficient. The short pallet arms provide a very large pendulum amplitude.

Mechanical clocks have always fascinated me. Building a traditional brass clock requires specialized equipment, but 3D printers have made it possible for anyone to build their own clock. I try to simplify the process while still maintaining a classic look. Construction only needs a few metal arbors cut to length plus a few screws and the 3D printed parts. This clock is accurate to a minute or two per week. Runtime is about 7.5 days per winding.

This guide shows the assembly process. Simple construction techniques require only a 3D printer and a few hand tools.

The design requirements for this clock are:

- 1) The clock must be accurate. This clock typically maintains an accuracy of 1-2 minutes per week.
- 2) The clock must be reliable. The deadbeat escapement used in this design has proven itself to be very robust. The stacked gears are fully isolated to reduce friction. The clock often starts ticking as soon as the weight is applied.
- 3) The clock must have a long runtime. Eight days is a reasonable length allowing for winding once per week. It could have been made longer, but this would come at the expense of reliability.
- 4) The clock must look good. I think the simple gear layout looks great. Hopefully, you like it as well.
- 5) The clock should be easy to assemble. This is my easiest to build pendulum clock. The bill of materials is as small as possible for a long running clock.

The clock can be printed on any machine with a 220x220mm (Ender 3) or 250x210mm (Prusa MK4) build plate. This includes nearly all 3D printers except the ones with "Mini" in the name. The two frame pieces are the largest components that determines the minimum printer size. The location of the winding key dictated a large 7.7" (196mm) dial that is too large for most mini 3D printers.

The total print time is around 35 hours on a Prusa MK4 style printer with input shaping. Around 0.9kg of PLA filament in a few colors is needed.

## Quick Start

This clock is designed to be easy to print and assemble. This manual will walk you through the process. Here are the most important steps if you want to get started right away.

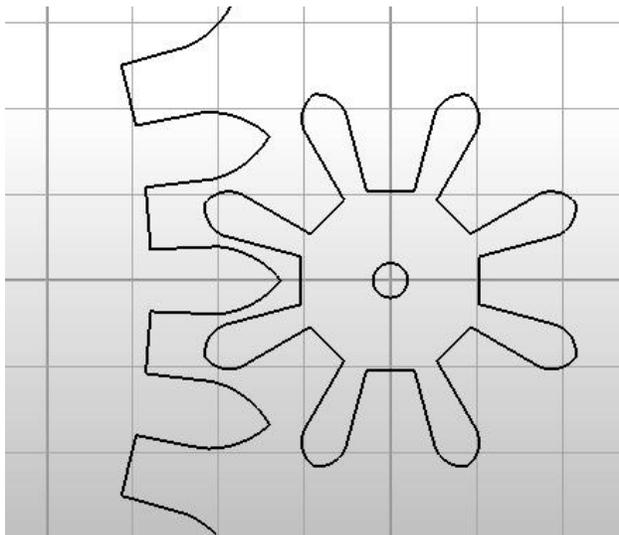
- 1) Order the non-printed components listed on page 15 and follow the metal cut list on page 16.
- 2) Pages 8-9 shows the exploded view of the entire clock.
- 3) Print the frame components listed on page 11 using 0.2mm layer heights and 4 perimeters.
- 4) Print the gears listed on page 11 using 0.15mm layer heights and 4 perimeters.
- 5) Print the miscellaneous components listed on page 13 using 0.2mm layers and 4 perimeters
- 6) Refer to the gear and spacer cross reference charts on pages 12-13.
- 7) Follow the pre-assembly cleanup steps shown on pages 17-19.
- 8) Component pre-assembly construction steps are on pages 21-28.
- 9) Run the pendulum free-swing test on pages 29-30.
- 10) The step-by-step process of adding the gears is on pages 31-35.
- 11) Weight shell information is on pages 36-38 after determining how much your clock needs.
- 12) Print the weight shell files listed on page 14.
- 13) Additional debug steps are on pages 40-42.

## Details

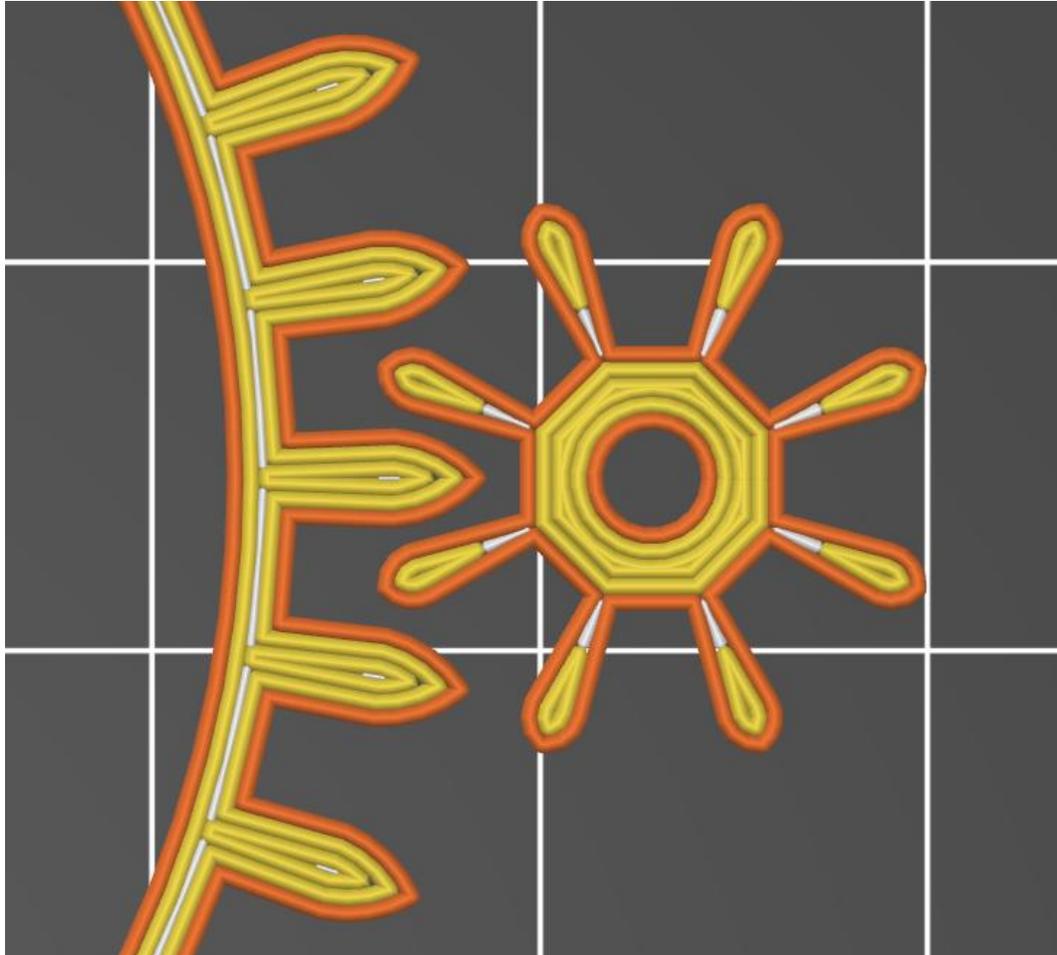
### Perfect Print Gears

The gears in this clock use a cycloidal tooth profile that has been optimized for 3D printing. I call them “Perfect Print Gears”. This gear style has evolved over several years to be extremely efficient for 3D printed clock gears. They start with a cycloidal gear tooth profile, then enhancements are added for printing. Many of my older clocks have been retrofitted with this gear style.

Below is a closeup of a traditional 40 tooth brass epicycloidal gear meshing with an 8 tooth steel pinion. It works great in brass and steel.



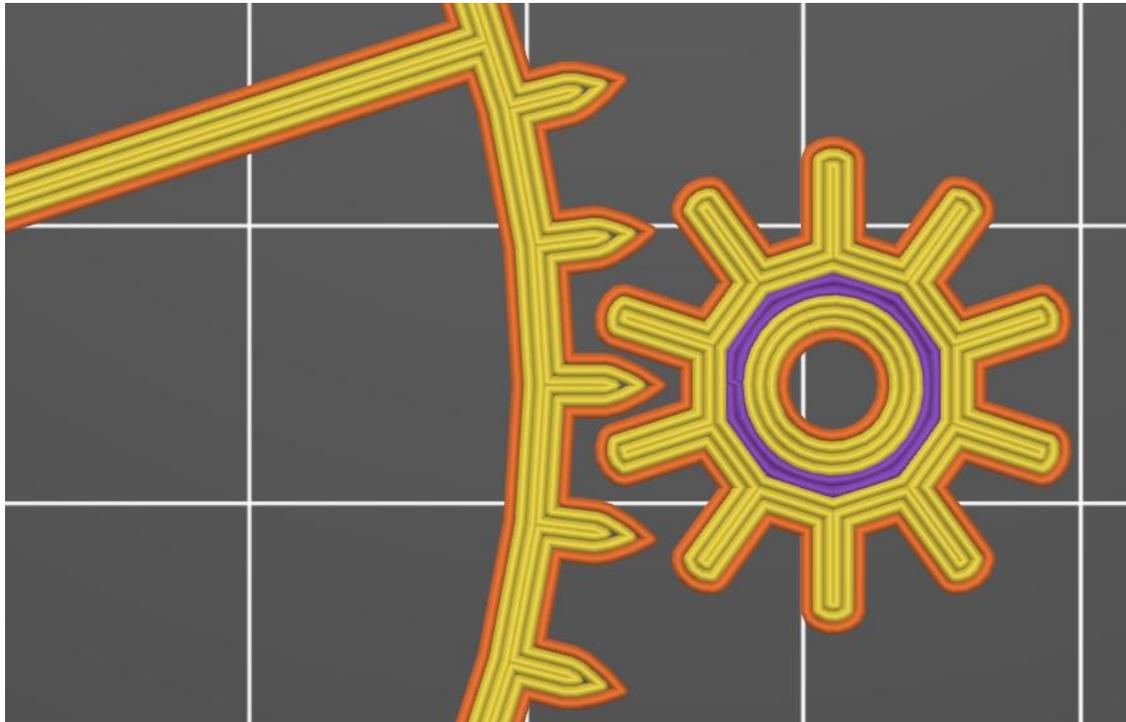
Unfortunately, the results are not so great when 3D printed. The slicer output is shown below. The large gear is acceptable, but the pinion is a mess. The pinion teeth are way too delicate and would certainly wear out quickly if they are made from the same material as the larger gears. The tiny white infill spots add extra retraction steps that lead to excessive stringing when printed.



Several changes are required to make these gears work in a 3D printer. The pinion needs to be made thicker to give it some strength. The main gear was made narrower to make room for the wider pinion. Backlash was also reduced. The result is better, but not perfect. The pinion leaves are still a bit weak at the base and each tooth requires several retractions while printing. The pinion would likely have extra stringing or blobs as it prints. Even the large gear has a few retractions to print the wide portion of each tooth.

The modifications for 3D printing were based on two primary criteria. The gears must have constant velocity and low friction. Constant velocity implies that if the input gear rotates smoothly, then the output gear must also rotate smoothly. Low friction is an obvious requirement for efficient power transfer. These two criteria work together. Gears designed with constant velocity will typically have low friction. A secondary design criteria is ease of printing. This is a desirable characteristic, but not necessarily required.

The gear tooth profile used in these clocks was designed with uniform width side walls that print cleanly and a tooth tip that provides constant velocity. The result is shown below. Notice the clean the filament paths. Most of the tooth engagement takes place with the primary tooth touching the pinion side walls after the line of centers, so friction is minimized. I call them “Perfect Print Gears”.



### Clock Overview

A pendulum clock is conceptually very simple. A spring or falling weight provides energy to a pendulum swinging at a constant rate, dependent only on length. A series of gears convert the periodic pendulum motion into a display for the hours and minutes. The challenge is to make everything work elegantly and accurately.

The basic design of this clock started over 10 years ago, but I needed a few years of practical experience to make it into a working clock. The central arbor has a “tower” of gears with 50, 48, and 45 teeth. The matching pinions have 10, 12, and 15 teeth. The lower arbor contains the ratchet and winding drum that powers the clock. The pallet sits on the central arbor with clearance holes around the lower arbor and frame.

The pallet was designed with a 4.5 tooth span on the 24 tooth escapement. This creates short lever arms to provide a large pendulum swing. The minimum required swing is about 3 degrees in each direction for a total travel of 6 degrees. The overswing increases the total travel to +/-5 degrees or 10 degrees total swing.

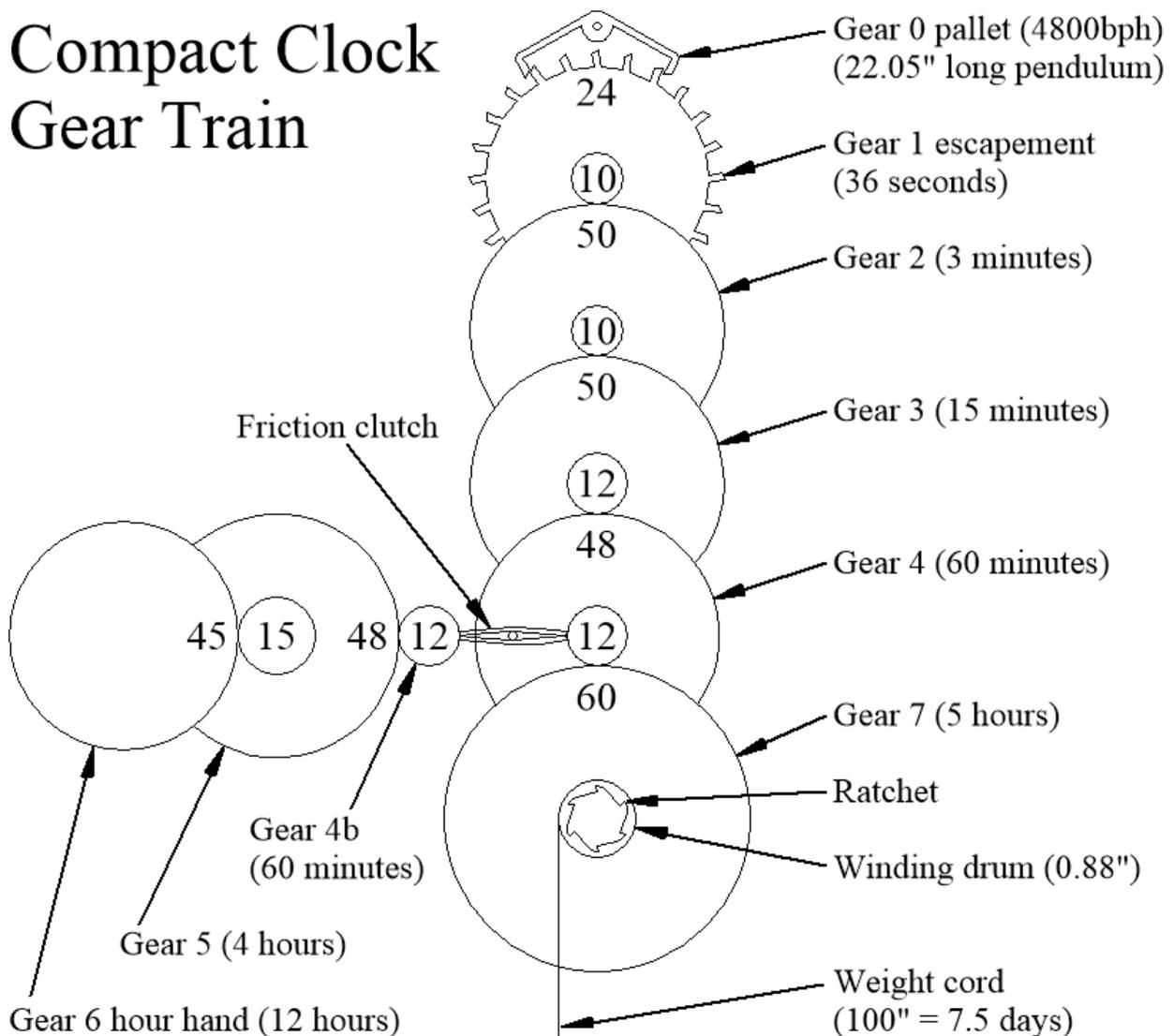
This clock uses simple gear tooth ratios throughout. The gears used include 50:10, 48:12, and 45:15 teeth. This creates easy to work with ratios of 5:1, 4:1, and 3:1. The winding drum needed a tiny bit more clearance so it uses a 60:12 tooth count with a 5:1 ratio.

Below is a diagram showing the overall gear structure used in the clock. The weight turns gear 7 once every 5 hours. Each gear in the train above gear 7 rotate at a faster rate until it reaches the escapement rotating every 36 seconds. The 22.05" pendulum sets the rate of 4800 beats per hour.

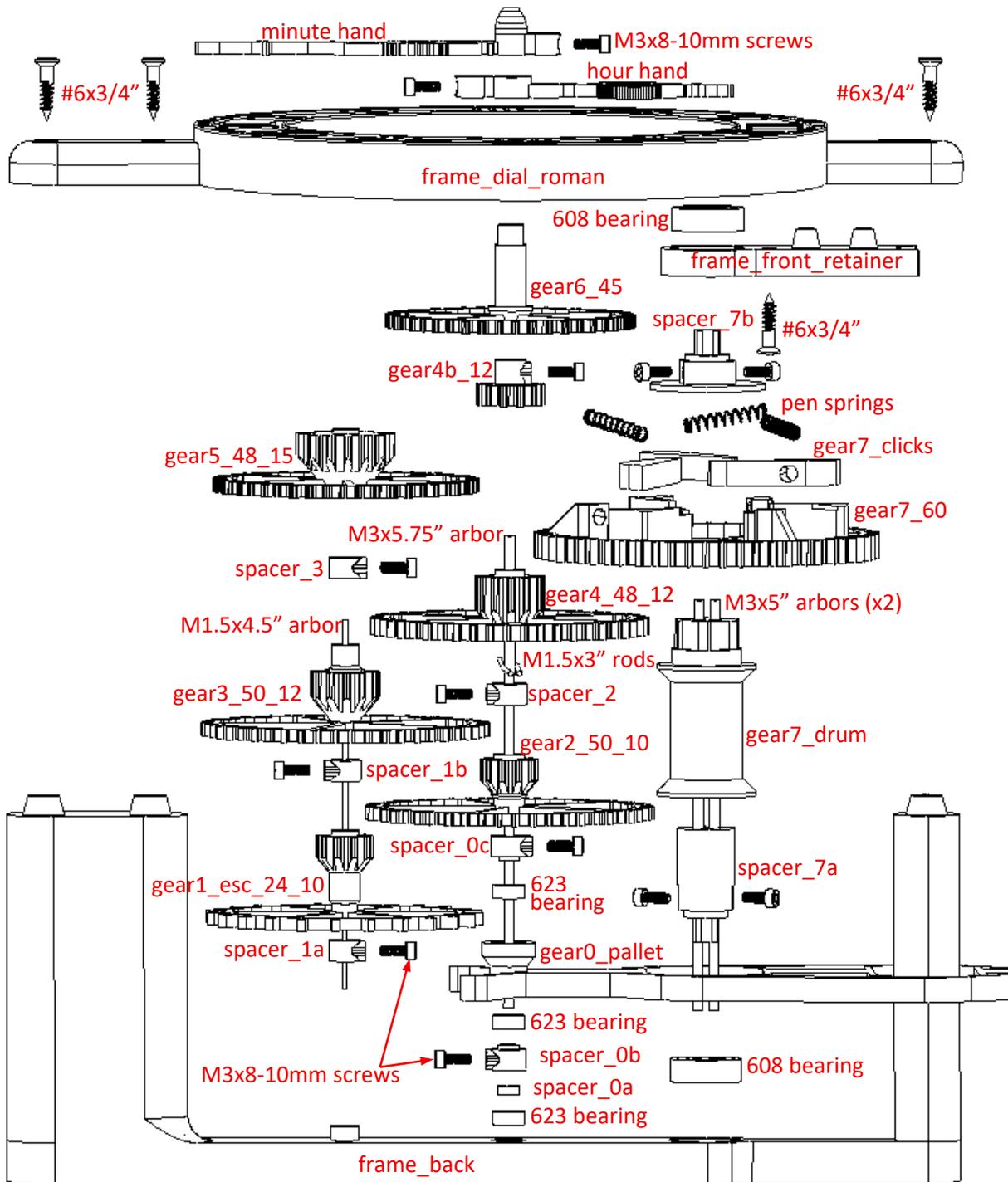
A new compact style friction clutch loosely connects gear 4b to gear 4 to rotate the minute and hour hands. The loose connection allows the time to be changed without affecting the gears powering the pendulum.

The winding drum has a diameter of 0.88", so 2.76" of cord will be released every time gear 7 rotates. If gear 7 rotates once every 5 hours, then 13.27" of cord will be released every day. A natural height to hang the clock allows about 50" of weight shell drop. A pulley is used to keep the weight shell centered around the frame so there is effectively 100" of total weight shell drop. 100" of drop divided by 13.27" of cord per day equals just over 7.5 days of runtime.

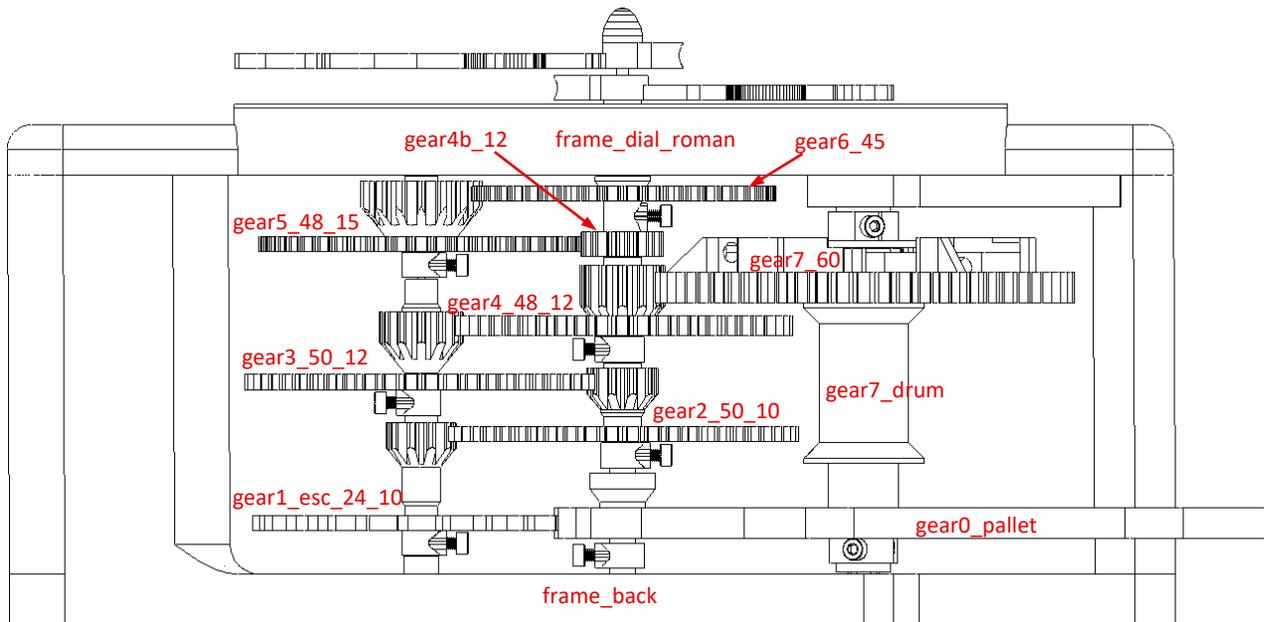
## Compact Clock Gear Train



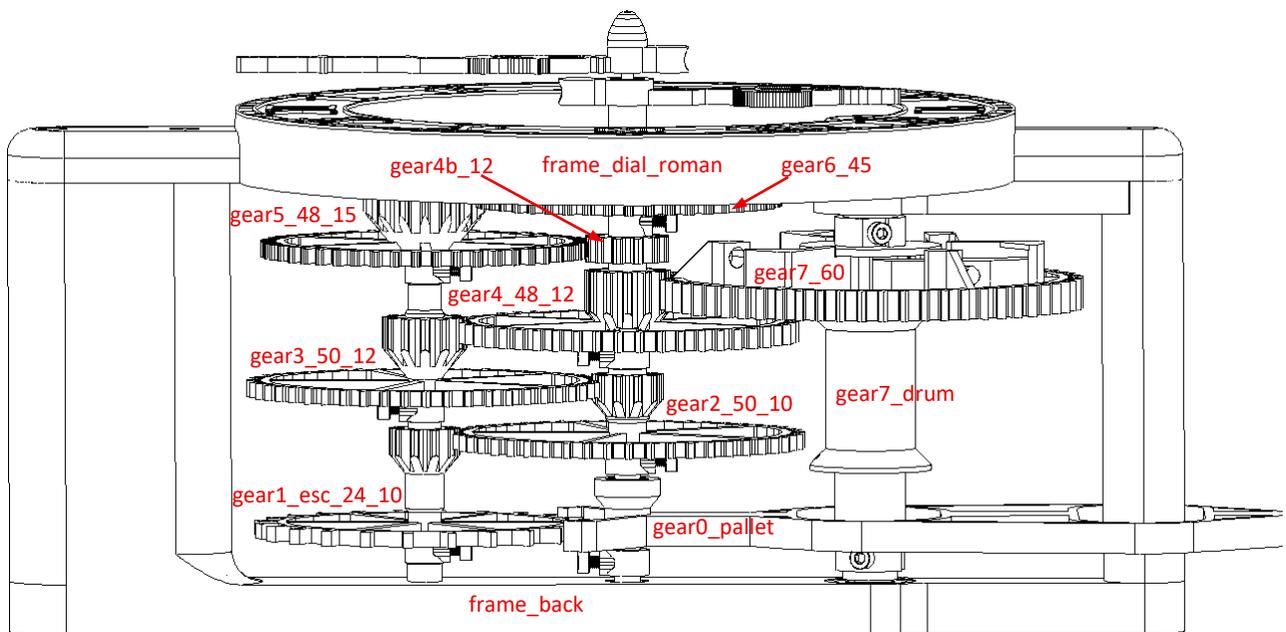
Here is an exploded view of all the components in the main body of the clock. All the gears stack on three primary arbors.



Here is side view without exploding the parts. The bearings and arbors end up hidden.



Sometimes it is easier to visualize with a slight isometric view.



## Printing the Parts

All parts of this clock are designed to be easy to print. Every gear has been optimized to print using smooth filament flows with minimal retraction and less stringing. A color change is needed for the dial. This can be done by inserting a pause in the slicer and manually changing filament colors.

The components to print for this clock have been divided into subdirectories in the zip file to keep parts organized. The frame, gears, and weight shell each have their own subdirectory. Everything else is in the misc subdirectory.

I use two printer presets for all of my clocks. Most parts use a preset with 0.20mm layer heights, except for the gears that should work better with 0.15mm layers.

Printer characteristics:

|                     |   |
|---------------------|---|
| Material            | PLA   |
| Nozzle Size         | 0.4mm   |
| Starting Preset     | 0.20mm SPEED in PrusaSlicer for most parts (gears use STRUCTURAL)       |
| Layer Height        | 0.2mm for most parts (gears should use 0.15mm)                          |
| Perimeters          | 4 for most parts  |
| Top Layers          | 7   |
| Bottom Layers       | 6   |
| Seam Position       | Random  |
| Scarf Joints        | Enable this feature if it is available in your slicer                   |
| Perimeter Generator | Arachne for most parts (gears should use Classic)                       |
| Fill Density        | 25%   |
| Fill Pattern        | Cubic or other strong infill pattern                                    |
| Elephant Foot       | 0.25mm (look at the slicer to determine what works best)                |
| Supports            | Never needed for any parts in any of my clocks                          |
| Orientation         | Usually already optimal. Some parts may need to rotate to fit your bed. |

Some of these settings may be overkill, but you only need to print the parts once and you will be able to enjoy the clock for many years. PrusaSlicer has default print settings for 0.15mm and 0.20mm layer heights. In addition, there is a SPEED and a STRUCTURAL setting for both layer heights. I have started using 0.20mm SPEED for most parts and 0.15mm STRUCTURAL for the gears. Taking a slightly longer time to print the gears is a small price to pay for the extra accuracy. Most other parts are less critical. Other slicers may have similar setups with slightly different names.

I print all my clocks on Prusa machines. Any modern printer can print these clocks as long as the bed is large enough. I use two printers working together to make everything go faster. One printer makes the frame and the other printer makes the gears. The first printer to finish starts printing the miscellaneous parts. The weight shell can be saved until after you test how much weight your clock needs.

Below is the lists of parts to print. The colors listed are what was used to print most of my clocks. You are free to go wild with any other colors you like.

## Frame Parts

The frame is often printed in a neutral color so the primary focus can be on the gears. The frame dial needs a few color changes for highlights. The frame can be printed using 0.2mm layer heights with 4 perimeters and 25% infill for strength. The back frame has two options. One has built-in mouse ear tabs to help keep the tall part stuck to the bed. They are designed to break away easily. The dial has two different faces, simple numbers or classic Roman numerals.

Open the slicer to view the layer heights needed for color changes in the dial. A color change at 15.4mm can be added to change to a bright white for the dial. Another color change at 17.2mm is needed for the numbers.

| Part Name            | Color                   | Print | Notes   |
|----------------------|-------------------------|-------|---|
| frame_back           | tan                     | 1     | Print one of these back frame components. frame_back_tabs has built-in mouse-ear tabs to help stick to the bed.   |
| frame_back_tabs      | tan                     |       |   |
| frame_dial_numbers   | tan,<br>white,<br>black | 1     | Print one of these front dials.<br>Needs a color change to highlight the numbers. An additional color change can be added to give the dial a bright white background. |
| frame_dial_roman     |                         |       |   |
| frame_front_retainer | tan                     | 1     | Small bearing retainer sitting behind front dial  |

Table 1: Frame components to print

## Gears

The gears will work better using finer 0.15mm layer heights. The thinner layers take slightly longer to print, but friction should be reduced because the layer line ridges should be smaller. Everything else in the clock works fine using 0.20mm layers.

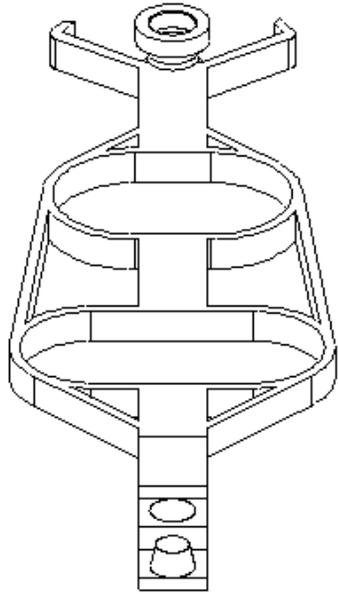
**IMPORTANT DETAIL:** The gears in this clock are designed to use the classic slicer. Some of my other clocks are optimized for Arachne, but the algorithm kept changing and adding in extra retractions. It became impossible to keep up with so many Arachne algorithm changes, so I switched the optimization back to the classic slicer. Everything except the gears can use Arachne if you want.

The gears print best using 4 perimeters, except the spacers that are optimized for 5 perimeters. Dual color silk PLA looks and works great. The cover photo uses red/gold silk PLA.

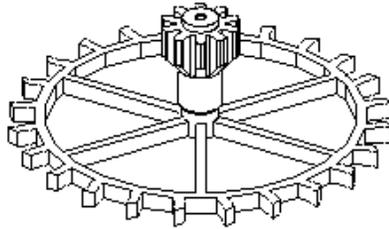
| Part Name       | Color    | Print | Notes   |
|-----------------|----------|-------|---|
| gear_spacers    | red/gold | 1     | All spacers in one file. Prints best with 5 perimeters        |
| gear0_pallet    | tan      | 1     | Large pendulum/pallet component looks best in a neutral color |
| gear1_esc_24_10 | red/gold | 1     |   |
| gear2_50_10     | red/gold | 1     |   |
| gear3_50_12     | red/gold | 1     |   |
| gear4_48_12     | red/gold | 1     |   |
| gear4b_12       | red/gold | 1     |   |
| gear5_48_15     | red/gold | 1     |   |
| gear6_45        | red/gold | 1     |   |
| gear7_60        | red/gold | 1     |   |
| gear7_clicks    | red/gold | 1     |   |
| gear7_drum      | red/gold | 1     |   |

Table 2: Gears to print

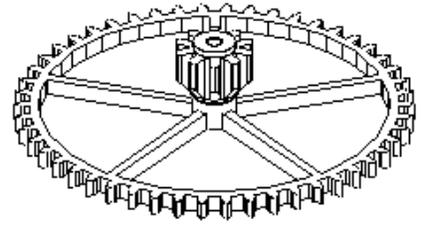
Here is a summary of the gears used in the clock. The names include the arbor number and gear tooth counts to help identify them.



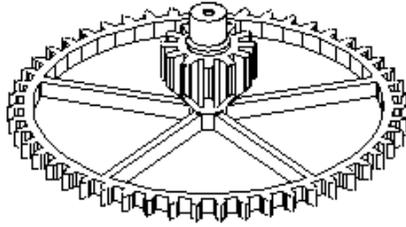
gear0\_pallet



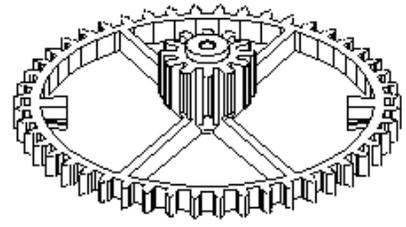
gear1\_esc\_24\_10



gear2\_50\_10



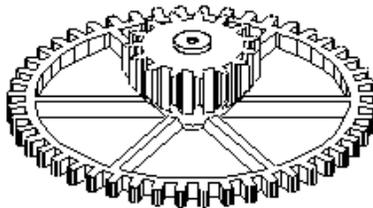
gear3\_50\_12



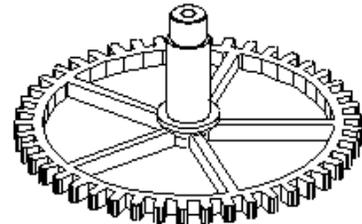
gear4\_48\_12



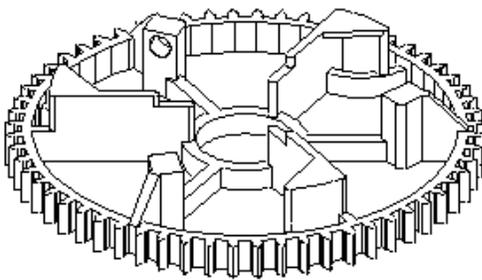
gear4b\_12



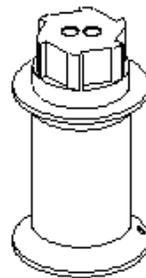
gear5\_48\_15



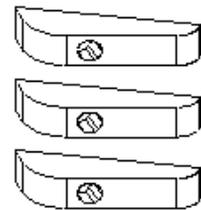
gear6\_45



gear7\_60

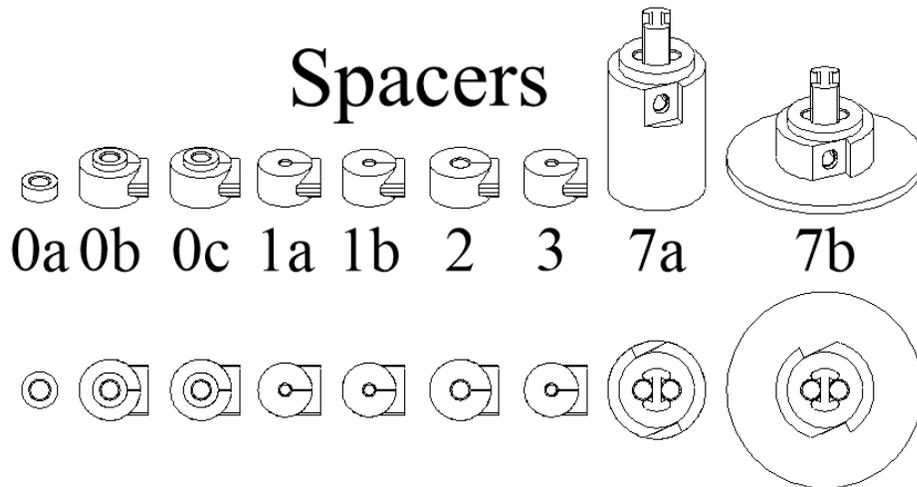


gear7\_drum



gear7\_clicks

Below is an image of the spacers used in the clock, shown in two orientations. They print as a single file, gear\_spacers.stl. They will be referenced in this document as spacer\_{arbor\_number}. The numbers in the diagram below indicate the gear each spacer is associated with. For example, spacer\_0a goes on the same arbor as gear0\_pallet. Several spacers are identical and interchangeable. For example, spacer 1a, 1b, and 3 all fit on the 1.5mm escapement arbor.



### Miscellaneous Parts

All the random parts used in the clock are included in the misc directory.

| Part Name          | Color        | Print | Notes   |
|--------------------|--------------|-------|---|
| hands_gothic       | black        | 1     | Select one of these hand styles. Use M3x8-10mm set screws to hold them in place. Spade hands need a color change. |
| hands_spade        | black, white |       |   |
| pendulum_arm_lower | tan          | 1     |   |
| pendulum_arm_mid   | tan          | 1     | See notes   |
| pendulum_bob_back  | copper       | 1     |   |
| pendulum_bob_front | copper       | 1     |   |
| pendulum_nuts      | tan          | 1     |   |
| screw_caps         | tan          | 1     | Optional plugs to cover the front frame screws  |
| swing_gauge        | black, white | 1     | Needs a layer change at 2.2mm   |
| winding_key_arm    | tan          | 1     |   |
| winding_key_knob   | copper       | 1     |   |

Table 3: Miscellaneous part to print

#### Notes:

The pendulum arm is composed of three segments. The upper segment is integrated with the pallet as gear0\_pallet (in the gear subdirectory). The lower segment is a fixed size with adjustment nuts to set the bob position. The default length of the middle pendulum segment should be the appropriate length for your clock. There are longer and shorter middle pendulum segments in the backup subdirectory that should only be needed if your clock needs extra adjustability. Use backup/pendulum\_arm\_mid\_long to slow down the clock and backup/pendulum\_arm\_mid\_short to speed up the clock. It is rare for a user to need anything except the default length pendulum\_arm\_mid.

## Weight Shell

The weight shell is the last component to be printed. It can wait until the rest of the clock is completed and you have tested how much weight is actually required. The highlighted rows show the components needed for a 2.8" diameter weight shell using a single extension. More details are later in this manual.

| File Name                | Color | Print    | Filament       | Notes                      |
|--------------------------|-------|----------|----------------|----------------------------|
| weight_shell_bottom_2p4  | Gold  | 0        | 10.88g         | 2.4" diameter weight shell |
| weight_shell_top_2p4     | Gold  | 0        | 96.05g         |                            |
| weight_shell_short_2p4   | Gold  | 0        | 81.17g         |                            |
| weight_shell_quarter_2p4 | Gold  | 0        | 47.32g         |                            |
| weight_shell_bottom_2p6  | Gold  | 0        | 14.05g         | 2.6" diameter weight shell |
| weight_shell_top_2p6     | Gold  | 0        | 107.32g        |                            |
| weight_shell_short_2p6   | Gold  | 0        | 90.12g         |                            |
| weight_shell_quarter_2p6 | Gold  | 0        | 51.98g         |                            |
| weight_shell_bottom_2p8  | Gold  | 1        | 17.49g         | 2.8" diameter weight shell |
| weight_shell_top_2p8     | Gold  | 1        | 119.19g        |                            |
| weight_shell_short_2p8   | Gold  | 0        | 99.56g         |                            |
| weight_shell_quarter_2p8 | Gold  | 1        | 56.81g         |                            |
| weight_shell_bottom_3p0  | Gold  | 0        | 21.34g         | 3.0" diameter weight shell |
| weight_shell_top_3p0     | Gold  | 0        | 132.04g        |                            |
| weight_shell_short_3p0   | Gold  | 0        | 109.72g        |                            |
| weight_shell_quarter_3p0 | Gold  | 0        | 61.62g         |                            |
| weight_shell_bottom_3p2  | Gold  | 0        | 25.62g         | 3.2" diameter weight shell |
| weight_shell_top_3p2     | Gold  | 0        | 145.49g        |                            |
| weight_shell_short_3p2   | Gold  | 0        | 120.36g        |                            |
| weight_shell_quarter_3p2 | Gold  | 0        | 66.52g         |                            |
| weight_shell_pulley      | Gold  | 1        | 4.76g          | Pulley used for all sizes  |
| <b>Total</b>             |       | <b>4</b> | <b>198.25g</b> |                            |

Table 4: Weight shell parts to print

## Additional Components

This clock consists mainly of 3D printed parts, but a few metal components are required to minimize friction so the clock can have a long runtime. The bill of materials has been reduced as much as possible. Several hard to find parts have been eliminated and the screws have been consolidated to a small number of sizes. The simple two piece frame reduces the number of wood screws considerably compared to all of my other clocks.

The non-3D printed components listed below are required. Part numbers from McMasterCarr are provided for some parts although many can be found cheaper at your local hardware store, Amazon, or eBay. Many parts can be substituted with the closest metric or imperial size. For example, the small arbors can use either 1.5mm (0.059") or 1/16" (0.0625") music wire. I prefer 1.5mm because a 1/16" (1.6mm) drill bit can be used to clean up the holes leaving the perfect amount of clearance.

Parts kits for all the non-printed parts except the weights are available on Etsy if you want to avoid finding all the parts. Check the main description where the model was purchased for a link.

| Qty             | Component                                  | McMC Part No.          | Notes  |
|-----------------|--|------------------------|--|
| 10              | #6x3/4" flat head wood screw               | 90031A151              | Metric equivalent is M3.5x20mm (4 extra screws are needed for each weight shell extension)         |
| 1               | #8x1-1/2" or #8x1-1/4" pan head wood screw | 90190A203<br>90190A201 | For mounting clock on wall, metric equivalent is M4.2x32-38mm                                      |
| 13              | M3x8-10mm socket head screws               | 91292A112              | 8mm or 10mm lengths will work  |
| 18"<br>(46cm)   | 3mm stainless rod                          | 1272T33                | Brass or plain steel rod should be OK. See cut list on next page                                   |
| 11"<br>(28cm)   | 1/16" or 1.5mm music wire or spring steel  | 89085K85               | 1/16" or 1.5mm diameters can be used. See cut list on next page                                    |
| 12'<br>(3.6m)   | braided fishing line                       |                        | I use PowerPro Spectra Fiber braided fishing line 65 lb. test. Other brands of braided line are OK |
| ~6 lb.<br>(3kg) | steel BBs or lead shot                     |                        | BBs are safer than lead shot and only need a slightly larger weight shell                          |
| 44              | pennies or washers                         |                        | Used in pendulum bob. Can also fill bob with BBs or lead shot                                      |
| 2               | 608 bearing (8x22x7mm)                     |                        | Generic skateboard bearings  |
| 3               | 623RS bearing (3x10x4mm)                   |                        | Used to support the pendulum   |
| 3               | click pen springs                          |                        | Used for ratchet   |

Table 5: Non-printed parts

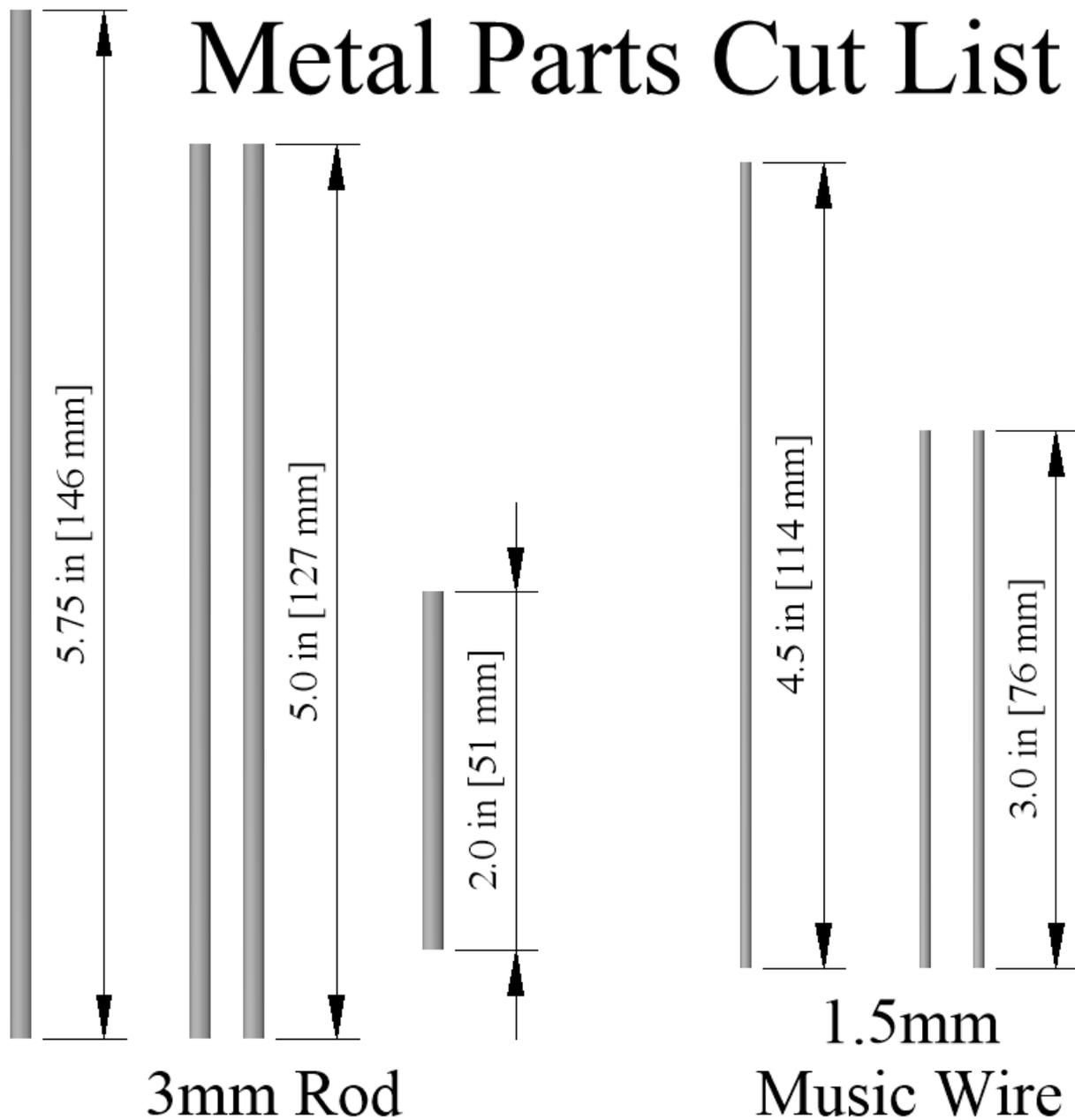
Ball bearings used to support the pendulum are critical to reduce friction on the fastest moving part. I find that cheap 623RS bearings available for around US\$8 for 10 work great. The rubber seal is easy to remove for cleaning out the thick factory grease. The larger 608 bearings used in the winding barrel are commonly called skateboard bearings. Any quality is acceptable since they rotate very slowly.

## Metal Cut List

The following diagram can be used to cut the metal parts. The escapement arbor uses a small diameter 1.5mm or 1/16" music wire to reduce friction. Music wire needs to be cut with a hardened cutter.

All other metal rods are 3mm in diameter. Stainless steel works best, but brass or plain steel should also work. The 623 bearings need to fit over one end of the 5" long arbor. Reduce the diameter by using a drill and a piece of sandpaper if needed so the bearings will fit.

The only machining required is cutting the arbors to length and cleaning up the ends. The diagram below is approximately to scale. Clean the ends by rotating them against a bench grinder or sanding disk.



## Component Pre-Assembly

**IMPORTANT:** This section will guide you through the process of getting the components ready to build the clock. You may be eager to rush in and start putting the clock together, but more effort spent in this section of the assembly process will reduce debug time later.

You will need:

- 3D printed frame parts
- 3D printed gears
- 3D printed pendulum arm and bob
- Pennies or small weights for the pendulum bob
- Screws and bearings from the “additional components” list on page 15
- Phillips head screwdriver
- Hex key to match M3x8-10mm screws
- Cut metal arbors with the ends de-burred
- 1.6mm (1/16”) drill bit
- 3.2mm (1/8”) drill bit
- Pin vise or slow speed hand drill

Optional tools:

- Sandpaper or small hand files
- Small hand clamp to hold the frame steady when inserting components

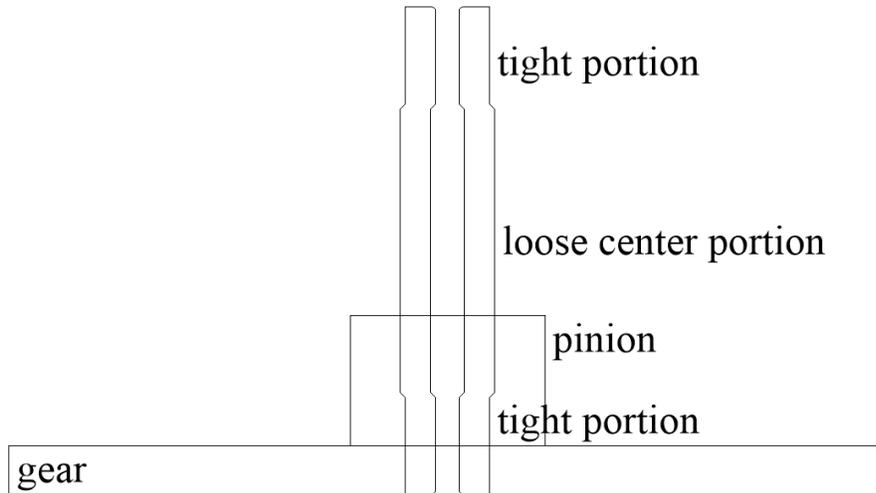
Most of the 3D printed parts will be assembled in this section, with the exception of the weight shell. It can be printed later after the clock is hanging and you can determine how much weight your clock needs to run reliably.

## Component Pre-fit

The most important step in reducing friction is to dry-fit the components and make adjustments as needed. The first step is to drill the arbor holes to the proper sizes. 3D printers often make holes smaller than expected. The easiest solution is to ream them to the proper fit. I use small pin vises to manually drill through the center of each gear. A power drill will also work, but go slowly to avoid melting the part.

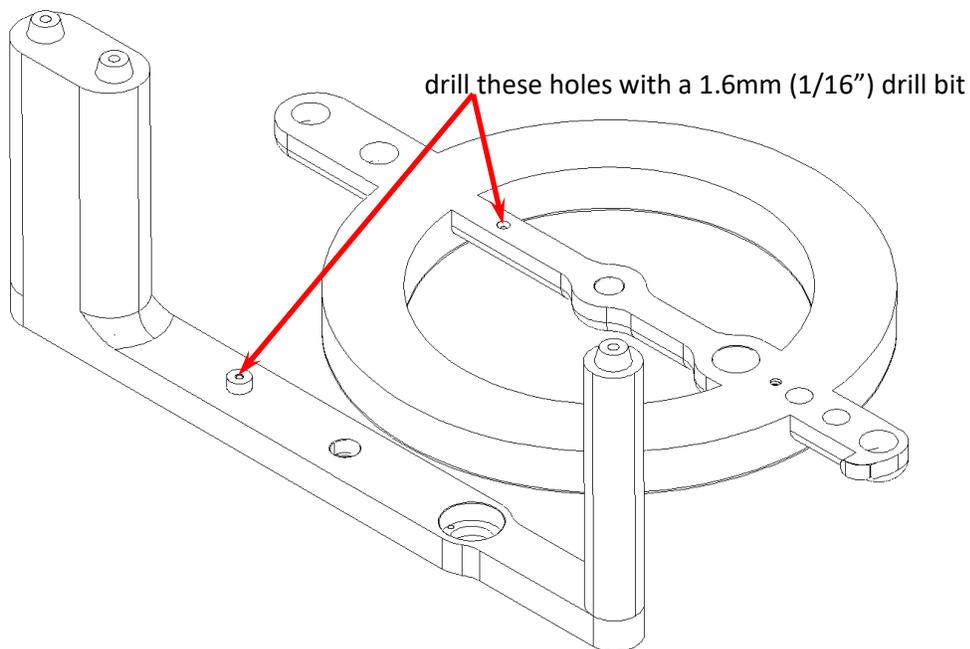


Drill the ends of every gear to the proper size. The gears are designed so only a short portion from each end needs to be drilled out. The middle portion opens up to provide extra clearance around the arbor. Use a 1/16" or 1.6mm drill bit for the 1.5mm arbors and a 1/8" or 3.2mm drill bit for the 3mm arbors. This provides the proper amount of clearance without being too loose.



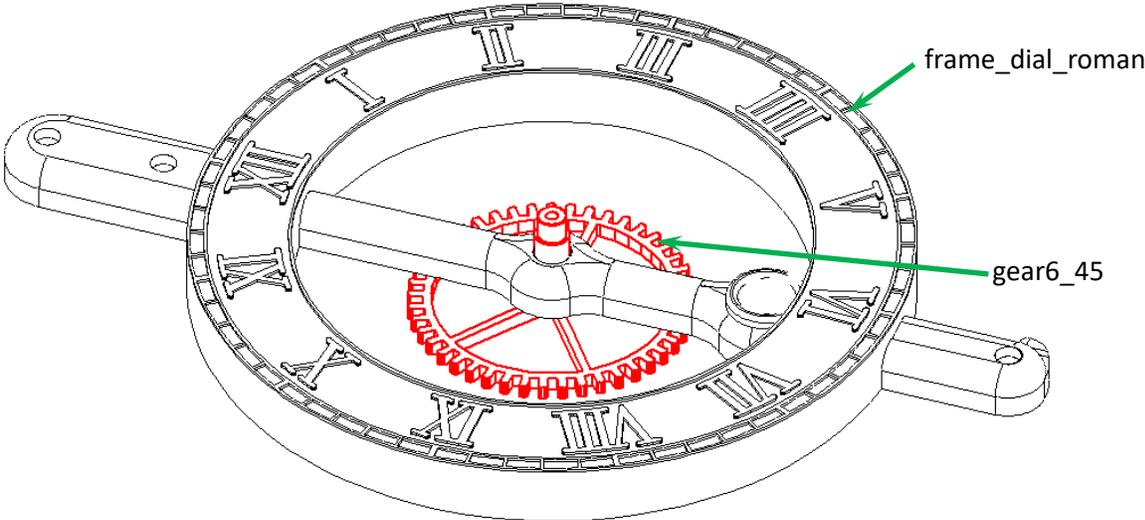
Drill both ends and blow through the hole to clean out the swarf. Test each gear by spinning it on an arbor. Gears with properly sized holes should spin for around 10 seconds. If it slows quickly, then drill it again. It will be obvious when the hole has enough clearance and friction has been reduced to the minimum.

The escapement arbor is the only arbor sitting directly inside the frame. All gears rotate around the arbor, but it is good if the arbor also rotates inside the frame.

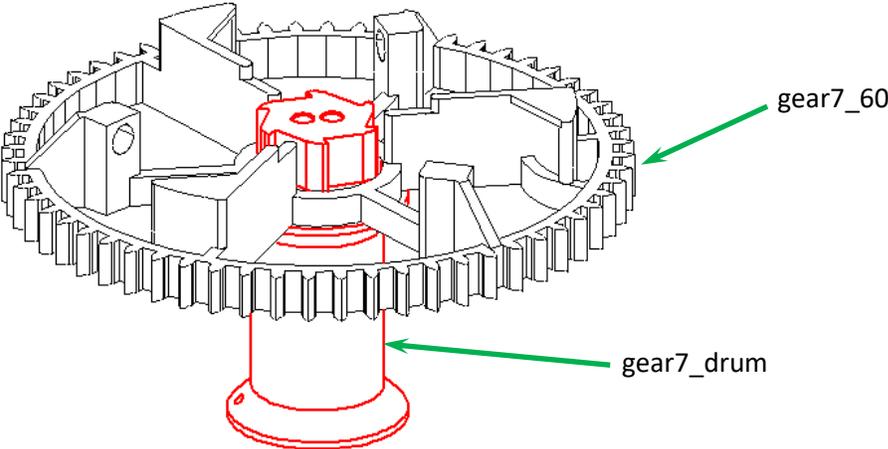


There are a few 3D printed parts that need to move inside other printed parts when the clock is running. They need to be checked for the proper fit and adjusted if needed. Use hand files or sandpaper to adjust the sizes of either component until the parts rotate smoothly. These parts involve PLA rubbing against PLA, so feel free to add a light coat of lithium grease to the sliding parts.

Gear 6 (hour hand gear) needs to rotate where it passes through the dial. Gear 6 is highlighted below in red. It rotates slowly, but excess friction here may allow the pendulum to swing, but the hands will not move.



The ratchet on the winding drum needs to rotate inside gear 7.



## Notes on Friction

It is worth stating how important it is to reduce friction in a mechanical clock. My clock uses 6.5 pounds of weight falling 50" every 7.5 days. The pendulum will tick 864,000 times in 7.5 days, so the energy of the weight shell dropping one inch (2.54cm) needs to provide enough energy to keep the pendulum swinging 17,280 times. This gives us an idea about how little energy is available to keep the clock ticking. There is not much room for wasted friction.

This clock laughs at YouTube videos showing a standalone clock escapement with a wrench or other heavy object hanging on a string and you can visibly see the weight dropping with each tick. It makes a good display and the pendulum amplitude is usually quite strong. However, a complete clock would need a huge drive weight or have a really short runtime if the escapement used that much energy. Everything needs to be much more efficient to build a clock that will run for 7.5 days.

Another way of looking at the energy in the clock is to calculate the forces at various places. My clock runs great using a 6.5 pound weight. The pulley reduces this to 3.25 pounds of force at the winding drum with a distance of 0.44" from the pivot point. The outer rim of gear 7 is 2" away from the pivot point, so it only has 0.715 pounds of force at the teeth. The next gear has a 4:1 reduction with only 0.18 pounds of force at the teeth. By the time the gear train makes it to the escapement, there is around 0.1 ounce of force applied at the pinion and 0.02 ounces at the escapement teeth. There is very little margin for excess friction.

Make sure to complete the component pre-checks to minimize friction before moving on to building the clock. Another equally important friction test on the pendulum support bearings will be done later.

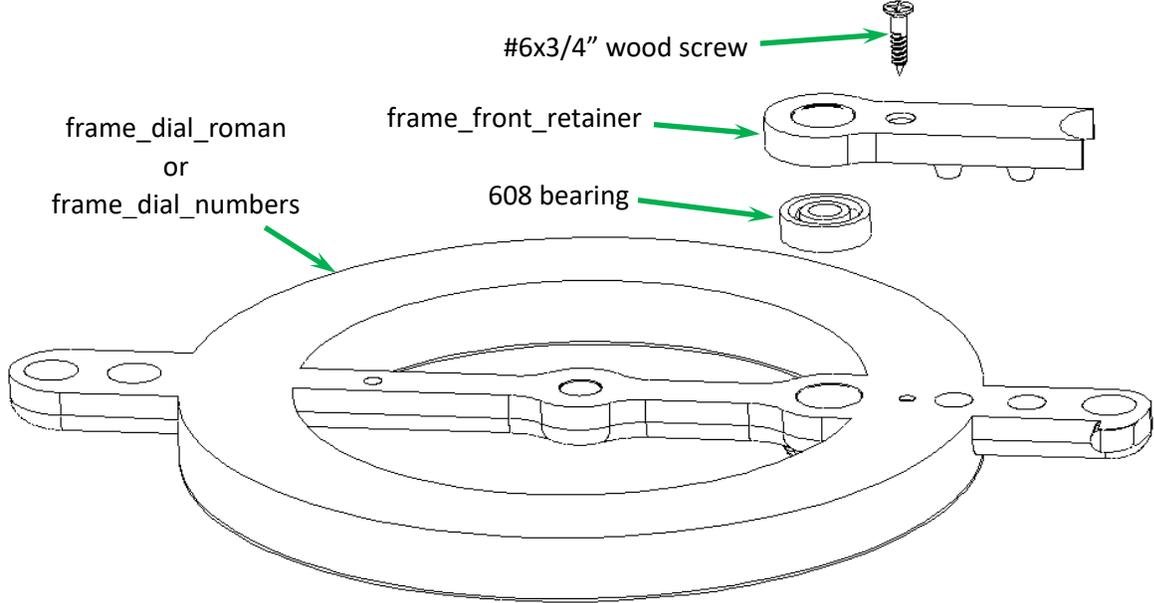
My clock uses 6.5lbs of drive weight. Your clock may require slightly more or less weight depending on overall friction in your clock. Hold off on printing the weight shell until you clock is closer to completion.

I sometimes add dry Teflon lubrication to all of the moving parts of the clock, but the clock also seems to run just fine without any lubrication. I have also used lithium grease on the pinions and pallet arms on some of my clocks. Just a tiny bit is needed. Apply it with a toothpick and wipe away most of it. It is generally considered a bad idea to oil or grease the clock gears because oil holds dust that can scrape the surfaces. I have not noticed any bad effects from greasing PLA clock gears, even after running for several years. PLA even seems to be safe with the solvent in dry Teflon lubrication, but try a small component before adding lubricants to the entire clock.

The small 623 bearings used to support the pendulum work best with the thick factory grease removed to minimize friction. Remove the rubber seals using a needle and wash the grease using solvent (paint thinner, mineral spirits, acetone, 90%+ alcohol, etc.). 91% isopropyl alcohol used for cleaning the print bed usually works for removing the factory grease from the bearings. Let them soak overnight and brush out the grease or use a blast of compressed air, then let them soak again in fresh alcohol. Add a drop of dry Teflon lubrication or lightweight oil to minimize rust if desired. Do not add powdered graphite lubricant to the bearings.

Frame Assembly

The frame on this clock is super simple. The only frame pre-assembly is adding the bearing holder to the front frame. Add a 608 bearing into the frame\_front\_retainer and attach it to the back of the dial using a #6x3/4" wood screw. The closest metric equivalent wood screw is M3.5x20mm. Other metric sizes that may work are M3x18mm or M3x20mm.

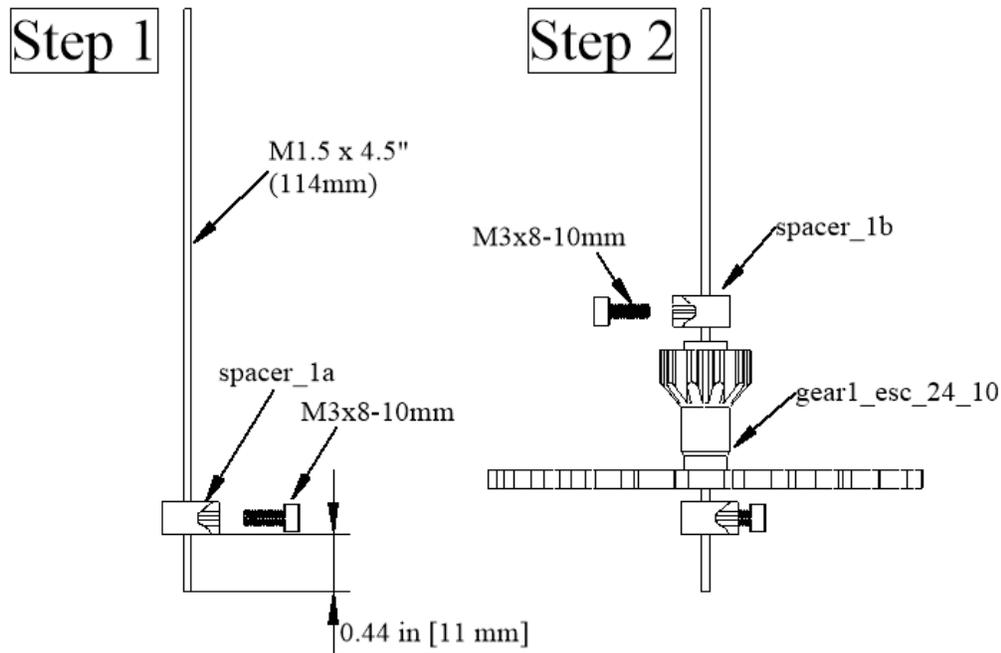


## Escapement Arbor Pre-Assembly

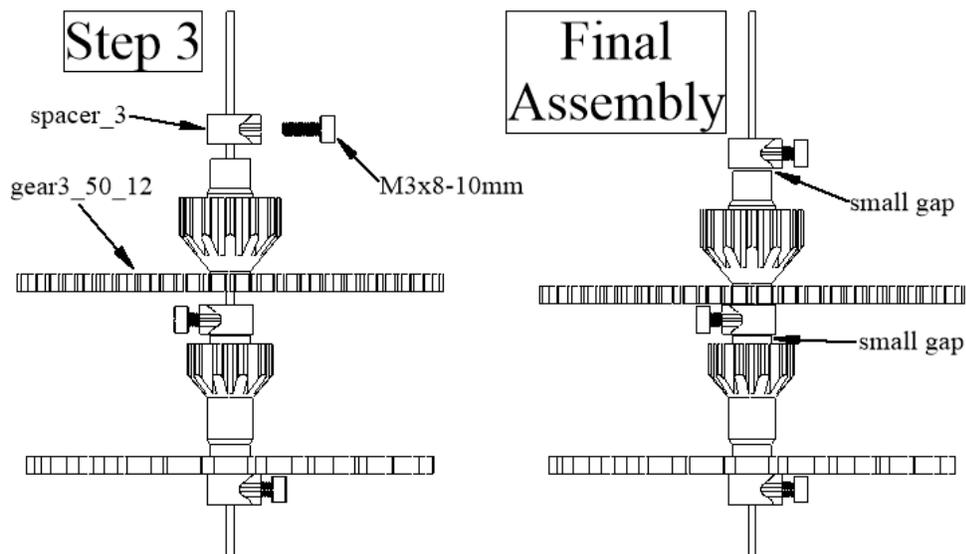
A few gears should be pre-assembled before adding them into the clock. The escapement arbor is first.

Step 1: Attach spacer\_1a to the M1.5 x 4.5" music wire arbor using a M3x8-10mm screw. The arbor should extend around 0.44" (11mm) below the spacer.

Step 2: Add gear1\_esc\_24\_10 and spacer\_1b to the arbor using a M3x8-10mm screw. Position spacer\_1b so there is a very tiny gap below it and the escapement is free to rotate. The set screw directions do not matter and they do not need to be very tight.



Step 3: Add gear3\_50\_12 and spacer\_3 using a M3x8-10mm screw. Gear 3 should rotate freely. The completed assembly is shown on the right. Both gears should spin freely.



## Pallet Arbor Pre-Assembly

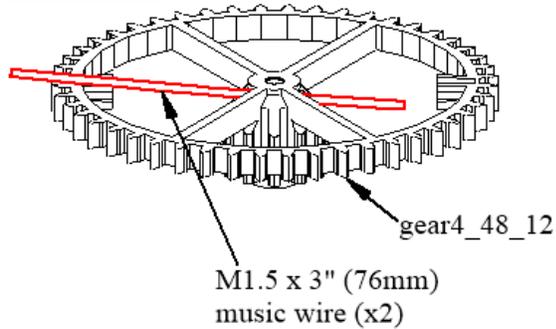
The pallet arbor includes the pallet, gear 2, gear 4, friction clutch, and gear 4b. Spacers will isolate the pallet and gears from each other.

Step 1: Add a piece of M1.5 x 3" music wire into gear4\_48\_12 by sliding it in from the bottom and clip both ends into the holders. The music wire will bend slightly, but should snap back.

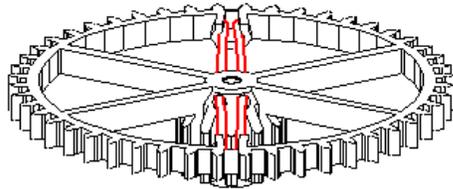
Step 2: Add the second piece of music wire into gear 4 so it looks like the diagram.

Step 3: Attach spacer\_0b to the M3 x 5.75" arbor using a M3x8-10mm screw. Make sure the narrow end of the spacer is pointing upwards. The arbor should extend 0.35" (9mm) below the spacer.

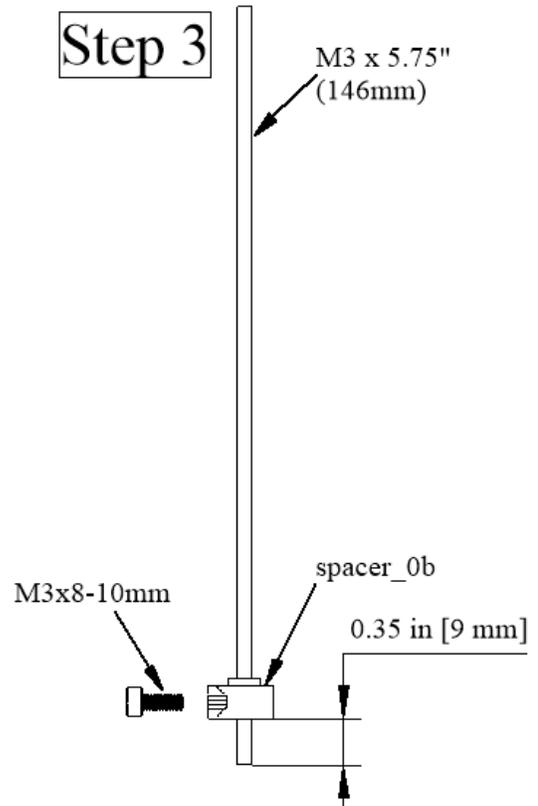
Step 1



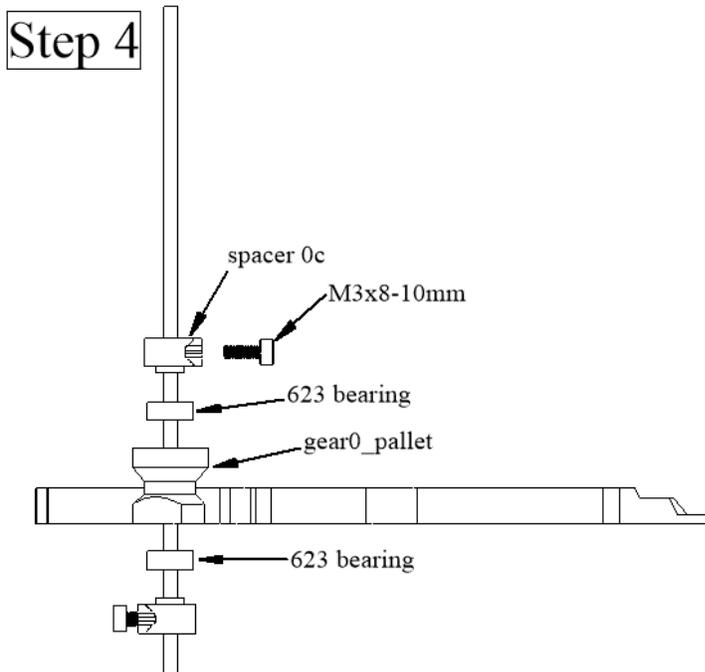
Step 2



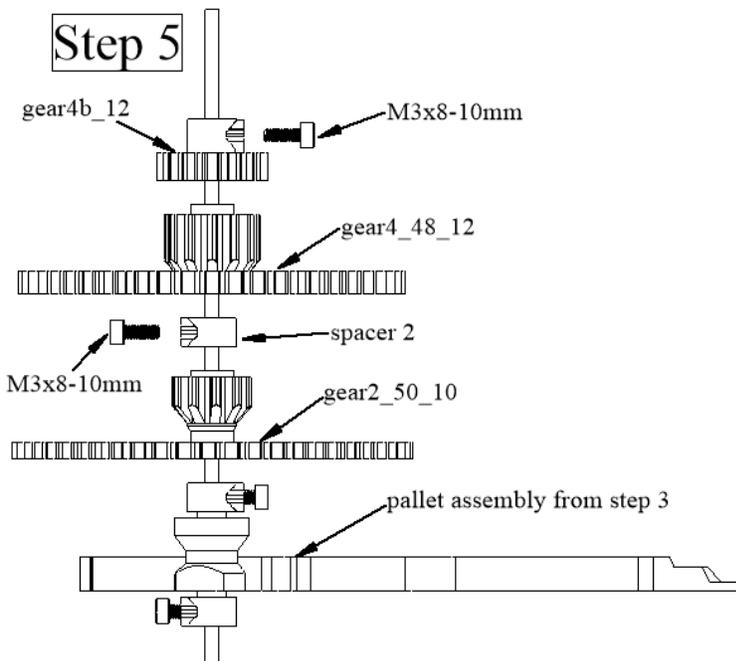
Step 3



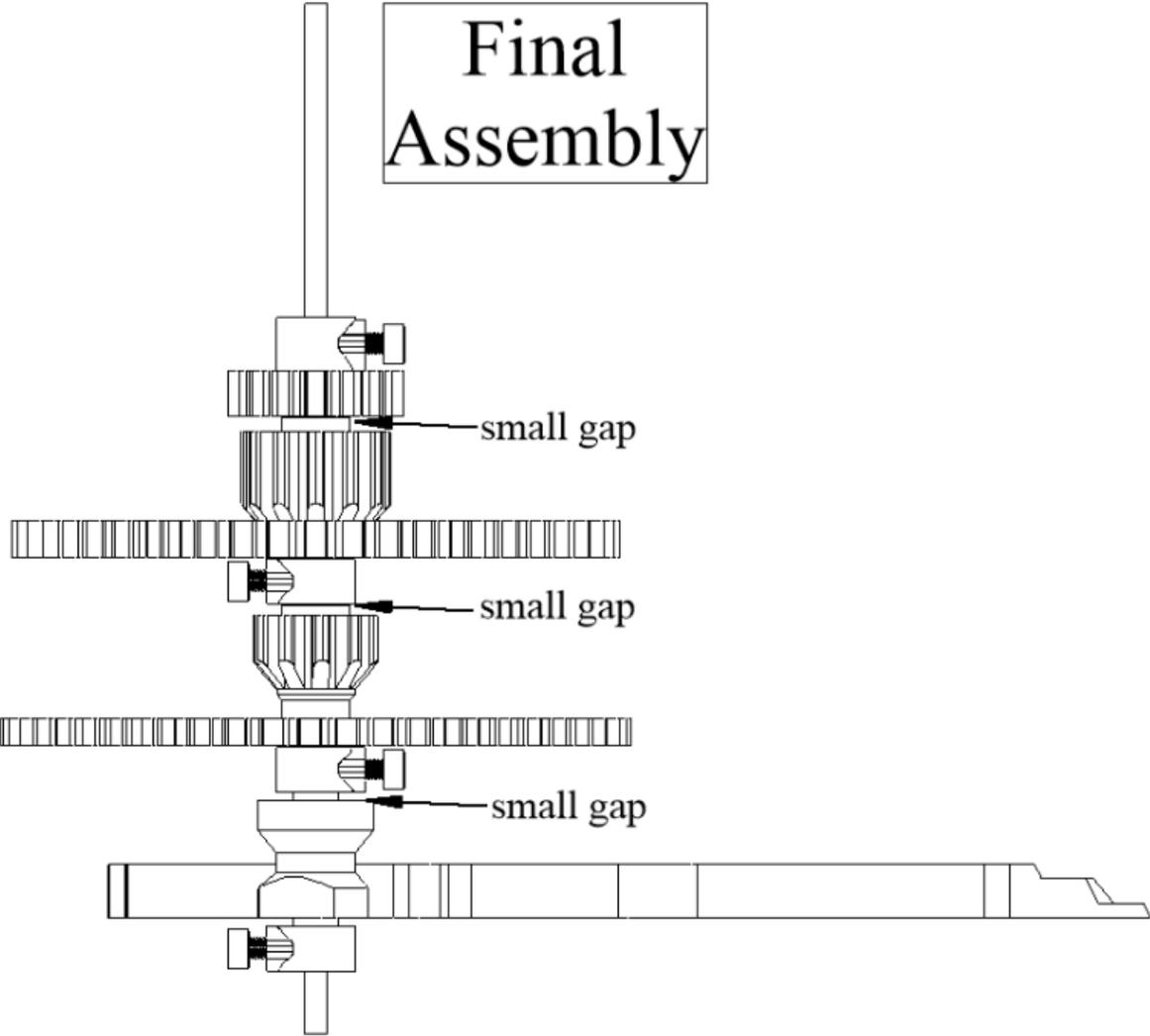
Step 4: Add components to the arbor in the order shown below. The 623 bearings should sit inside gear0\_pallet. The narrow end of spacer\_0c should face downwards. Tighten the set screw with a very tiny gap below the spacer. The pallet should move freely.



Step 5: Add gear 2, spacer 2, gear 4, and gear4b to the arbor in the order shown below. Gear4\_48\_12 includes the friction clutch used to allow the time to be changed while the clock is running. The music wire rods will be pushed apart when it is added to the arbor. The set screws should be positioned so there is a tiny gap below, allowing all gears to rotate freely.



The final assembly looks like the diagram below. The pallet and gear 2 should spin easily. Gear 4 will have a slight resistance from the friction clutch. It should hold position, yet spin with a slight pressure. The friction clutch is a new style designed for this clock. It needed to be very compact for so many gears to fit on the central arbor.

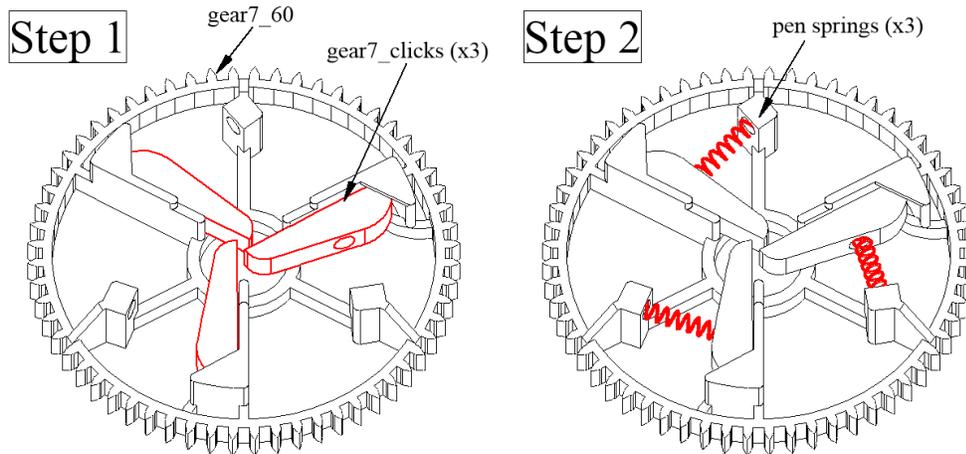


## Winding Drum Pre-Assembly:

The winding drum assembly combines the winding drum and ratchet onto a single arbor.

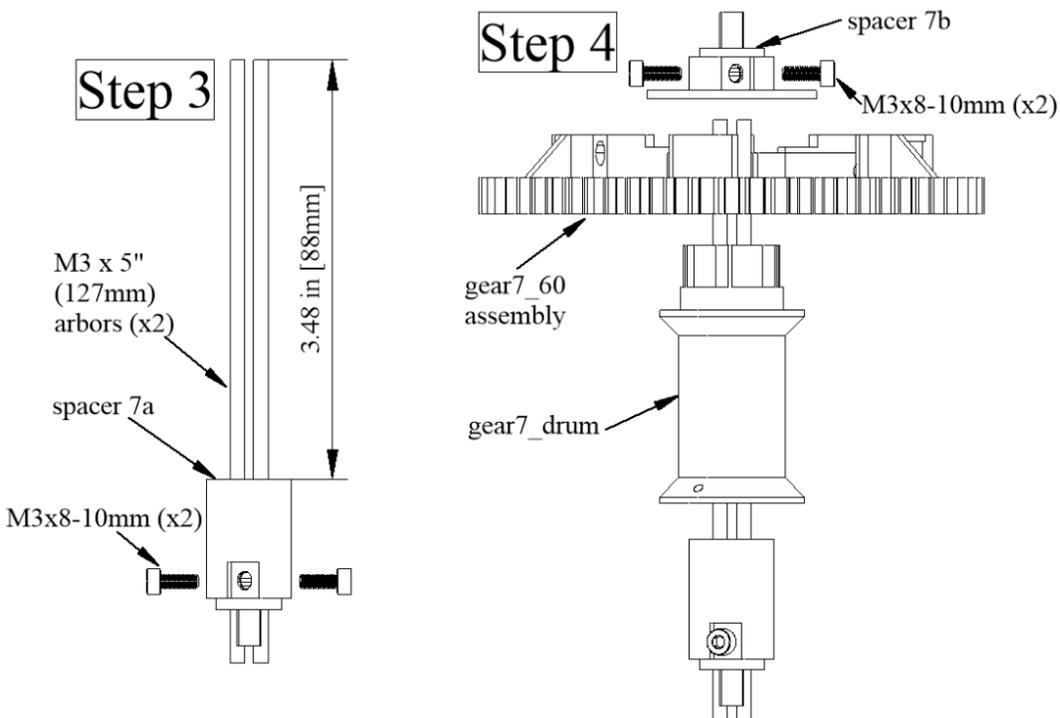
Step 1: Add three gear7\_clicks into gear7\_60 in the positions shown.

Step 2: Add three pen springs into the pockets between the clicks and the short columns. The springs will be at an angle pushing the clicks into position.



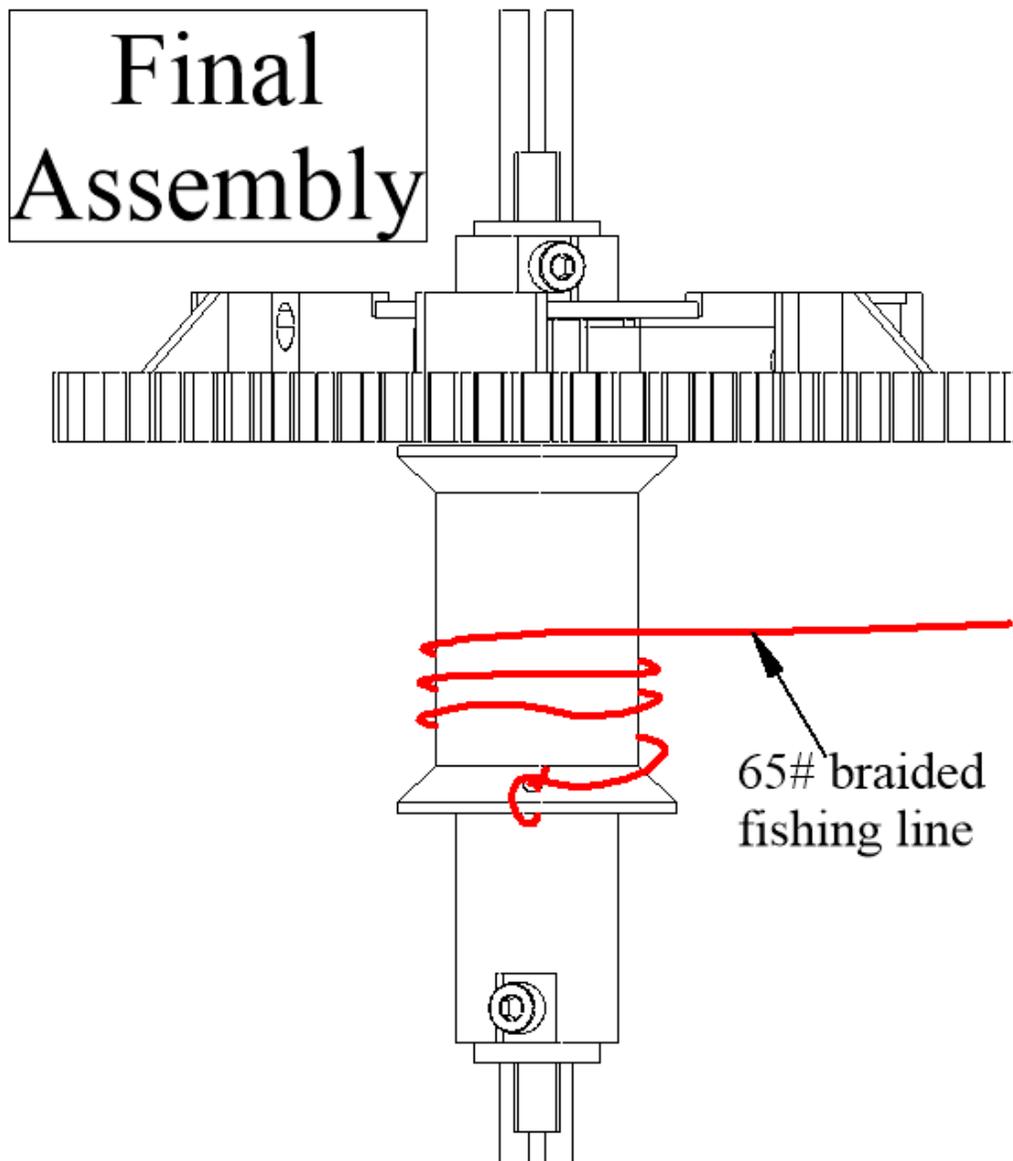
Step 3: Attach spacer\_7a to the two M3x5" arbors using M3x8-10mm screws. The top portion of the arbors should extend out 3.48" (88mm).

Step 4: Add gear7\_drum, the gear7\_60 ratchet assembly, and spacer\_7b to the arbors. Push the clicks to the side so the ratchet assembly can slide over the gear7\_drum. Spacer\_7b connects using two M3x8-10mm screws. Leave just enough of a gap for the ratchet to spin easily in one direction.

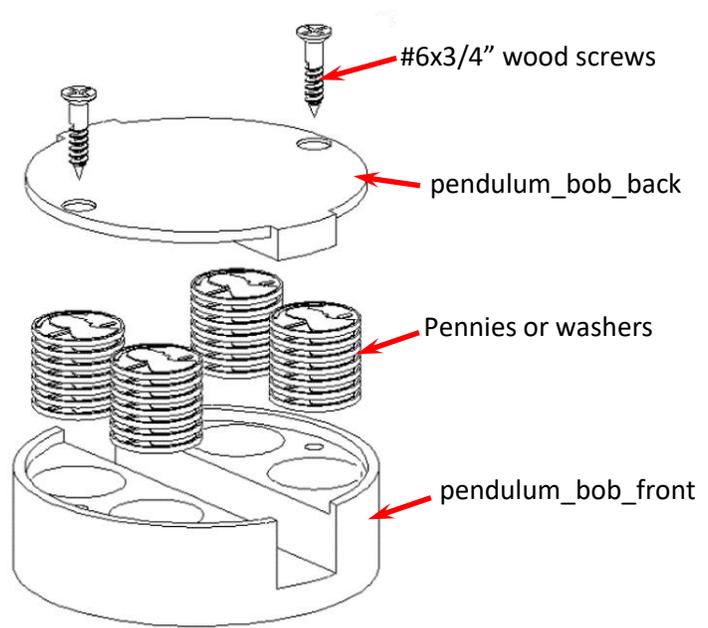


Final Assembly: The last step adds the cord to the drum. I use Power Pro Spectra Fiber Braided Fishing Line 65# or 80# strength. Many other types of thin strong cord should also be acceptable. Weight cord designed specifically for clocks is available at clock supply houses, but braided fishing line works just as well and is easier to find.

The drum will need 40-50 wraps of cord without piling up too much. Tie one end of the cord onto the small hole in the drum and cut the end short. Wrap the cord in the direction shown. Tie a loop in the other end of the line for attaching onto the frame when hanging the weight shell.

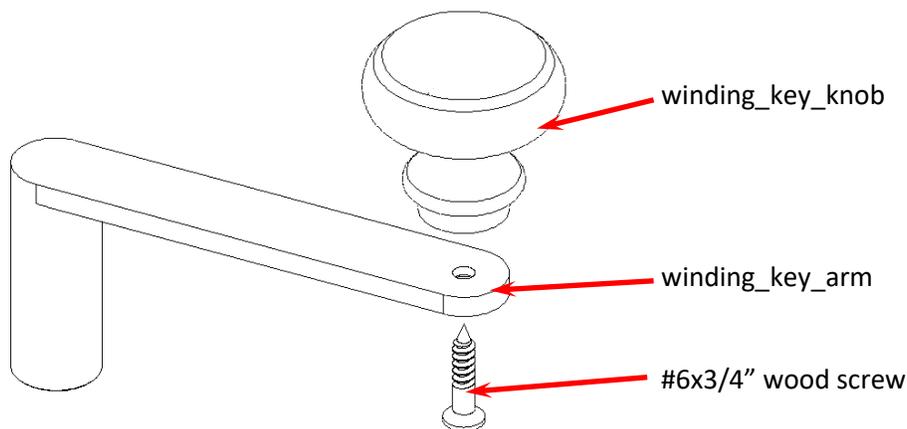


The pendulum bob is a two-piece shell filled with pennies or washers for weights. The actual weight is not a significant factor in regulating the time. A heavy bob and a light weight bob will both swing at approximately the same rate. It only needs enough momentum to continue swinging during minor disturbances and not be so heavy that it creates excess friction at the pivot point. The bob could be filled with washers, small rocks, or anything that fits. Pennies are cheaper than washers and they fit nicely. Secure the back of the pendulum bob with two #6x3/4" wood screws. The assembled pendulum bob on my clock weighs just over 6 ounces (170g). The bob slides over the lower portion of the pendulum shaft when assembled. Two printed nuts are used to adjust the length of the pendulum to set the rate. Start with the nuts positioned near the center of the available threads.



US pennies are being discontinued, so the pendulum bob can be filled with steel BBs or lead shot if desired. Fill the pockets for pennies and the additional holes around them. Any weight that comes close to 5-6 ounces (140-170g) is acceptable.

The winding key is a simple part that should have obvious assembly. Attach the winding\_key\_knob to the winding\_key\_arm using a #6x3/4" wood screw. Tighten the screw until it is secure, but still loose enough to spin easily. A small drop of oil could be added.



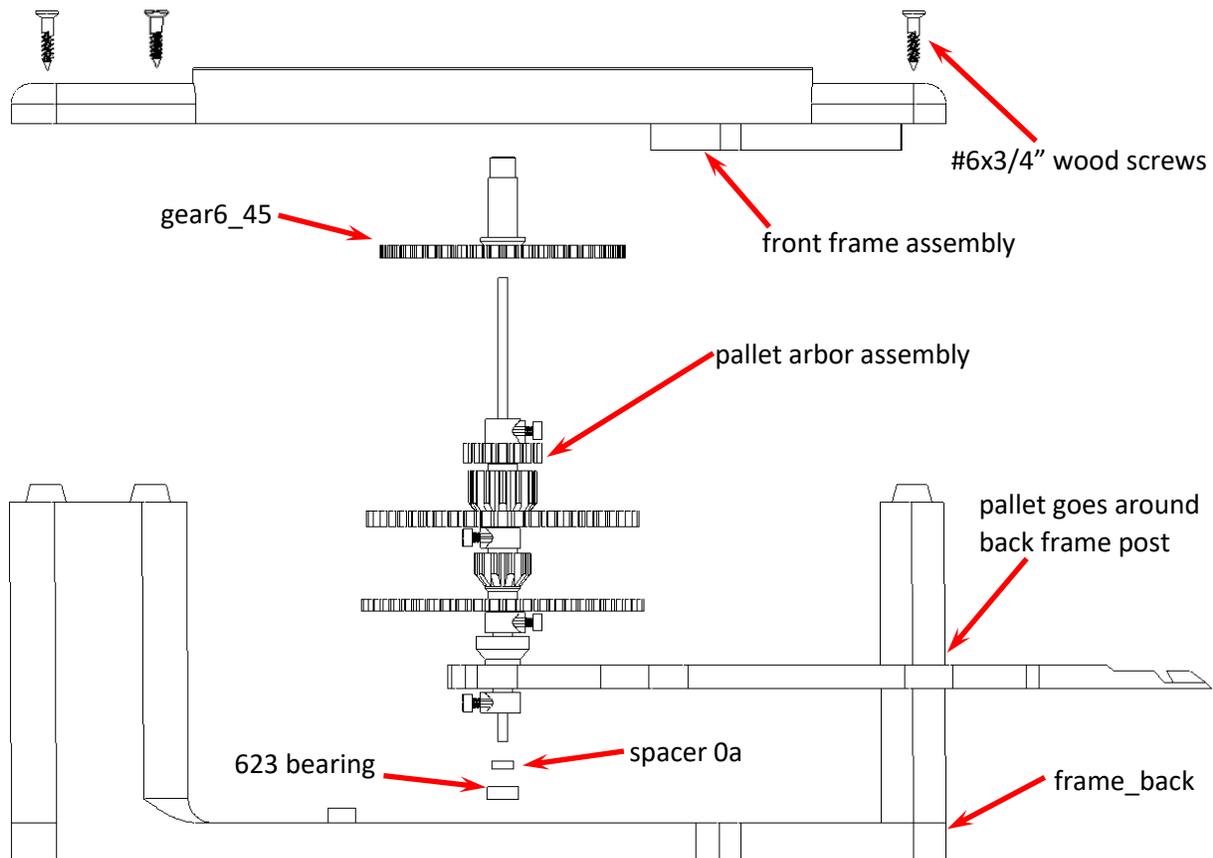
## Pendulum Free-Swing Test

All of my pendulum clocks use small ball bearings to support the pendulum. I find them to be extremely reliable and long lasting. Traditional clock designs use pendulum suspension springs that may have slightly lower friction, but they are hard to find and very delicate. Small ball bearings are much more forgiving for the typical hobbyist.

None of my experiments to find a better pendulum support have shown any better options. Emulating a traditional suspension spring using thread or guitar strings was promising, but a lot of effort for nearly the same performance as bearings. 3D printed knife edges would limit the runtime to a few days at best. I will continue using ball bearings as the most reliable option. My oldest clock is over 6 years old using a ball bearing pendulum support with no signs of wear. The pendulum amplitude is still as strong as it was when it was first built.

Most ball bearings come thick lubricating grease to function under heavily loaded conditions. The tiny 623RS bearings used for the pendulum are rated up to 18kg loads at 40,000rpm. We will be running them at significantly lower loads, but need to reduce friction by removing the thick factory grease. The rubber seals in 623RS bearings are easy to remove using a sharp pin. I use 90% IPA in an ultrasonic cleaner to loosen the grease. Other solvents like mineral spirits or acetone can also be used.

Testing the bearing friction is an important step to ensure your clock will run reliably. Assemble the pallet arbor and gear 6 into the frame as shown below.



Hang the assembly on the wall and add the pendulum. Pendulum\_arm\_mid and pendulum\_arm\_lower should drop onto the pallet arm. Add the weighted bob and the pendulum\_nuts. Sometimes the pendulum arms warp into a slight banana shape causing the bob to rub against the wall. They can be gently bent to provide clearance away from the wall if needed.

Move the pendulum all the way to one side and release it. Measure how long it takes for the amplitude to reduce from the original 8-10 degrees of swing in each direction down to a small amount. Good clean bearings should allow the pendulum to swing for at least 10 or 20 minutes. If the swing time is less than 10 minutes, then try swapping the bearings or cleaning them again. I usually purchase the cheapest bearings I can find on Amazon, eBay, or AliExpress and have never found a set of 10 bearings with more than 1 or 2 bad bearings. There is no need to buy super expensive ceramic bearings for the light loads used in this clock.

Don't start assembling the clock until all of the previously listed pre-checks have been completed.

Pre-check summary:

- 1) Visually inspect the gears for defects like elephant foot or excess stringing
- 2) All gears spin on their arbors
- 3) All arbors spin in the frame arbor holes
- 4) Gear 6 fits through the front dial and spins easily
- 5) The ratchet is working with minimal resistance
- 6) Pendulum bearing free swing test runs for at least 10 minutes, preferably closer to 20 minutes
- 7) All arbors have some end shake inside the frame

If all of these pre-checks are good, then it should be OK to start the final clock assembly. The most common issues that might cause the clock to be non-functional are the bearing free-swing test, excess friction on arbors, or lack of end shake.

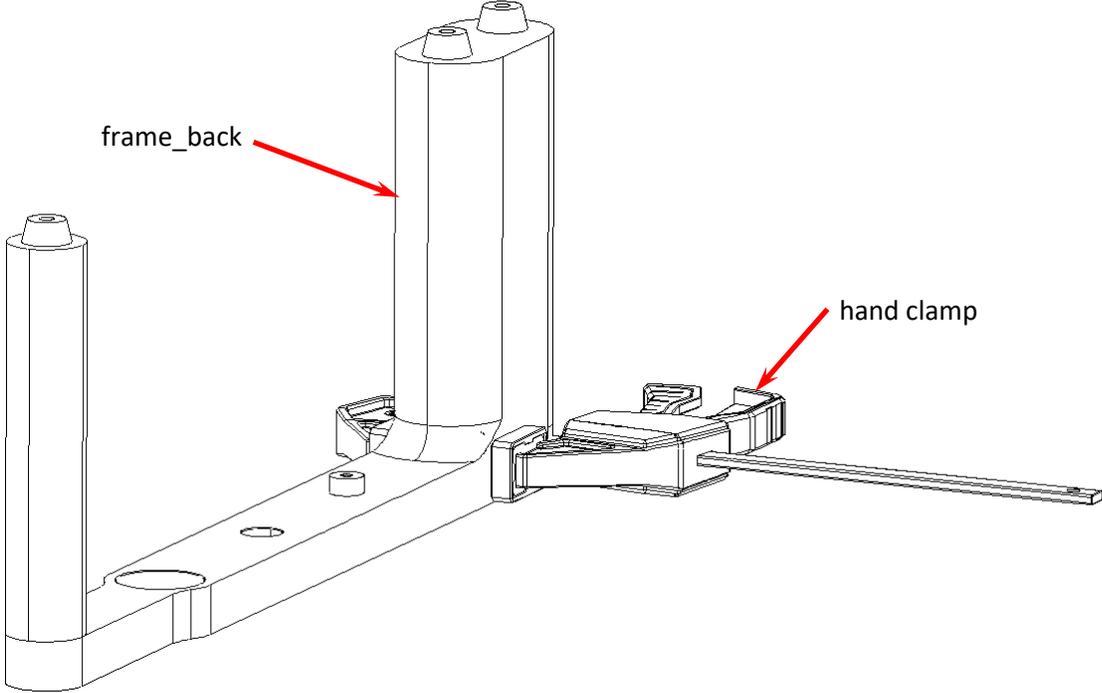
# Building the Clock

Most of my other clocks can be assembled by adding gears one by one into the back frame. This clock is different since many gears are pre-assembled onto the two primary arbors. The easiest solution is to mesh the gears together and add the two upper arbors at the same time.

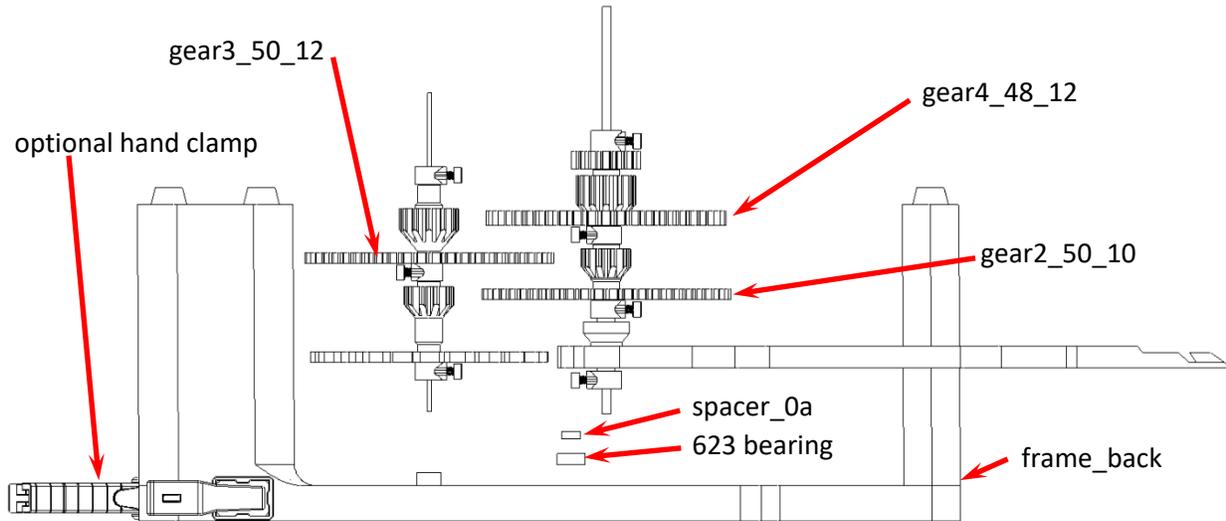
The narrow back frame in this clock likes to tip over when set flat on the workbench. A small hand clamp is helpful to hold the frame steady when assembling the clock. This is my favorite style. There are many others that should work just as well.



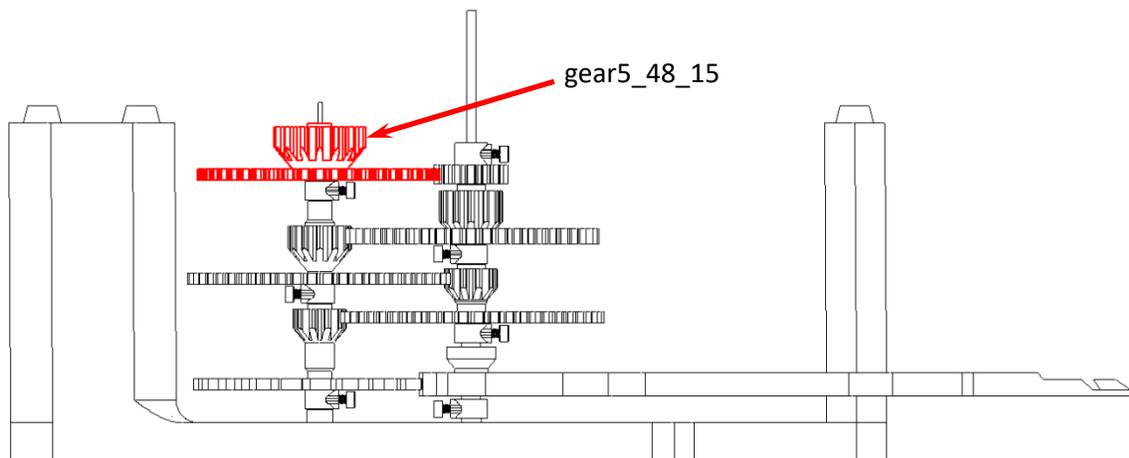
Add the clamp around the upper section of the frame to hold it steady.



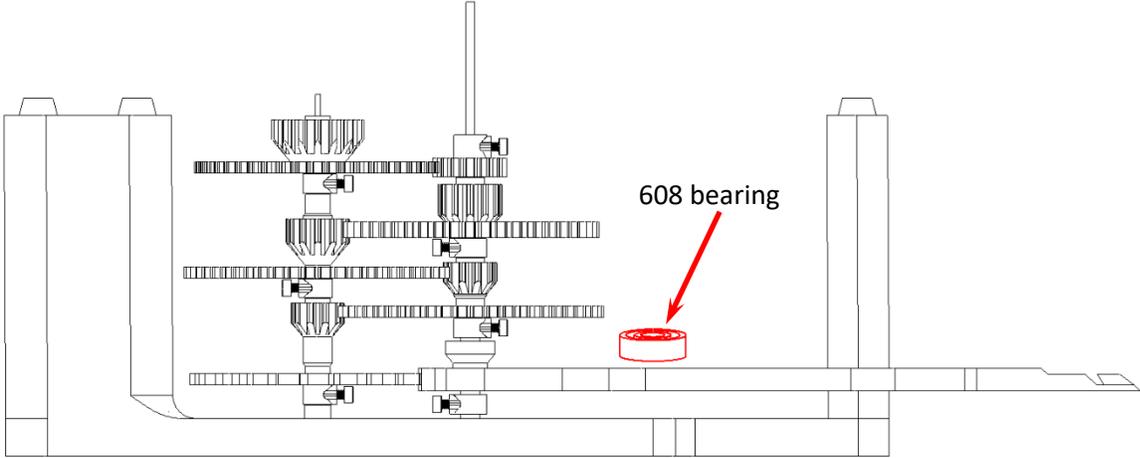
Add the two upper gear assemblies into the back frame. Start by placing a 623 bearing into the frame. Add the small spacer\_0a. Place gear 3 on the escapement arbor between gears 2 and 4 on the pallet arbor.



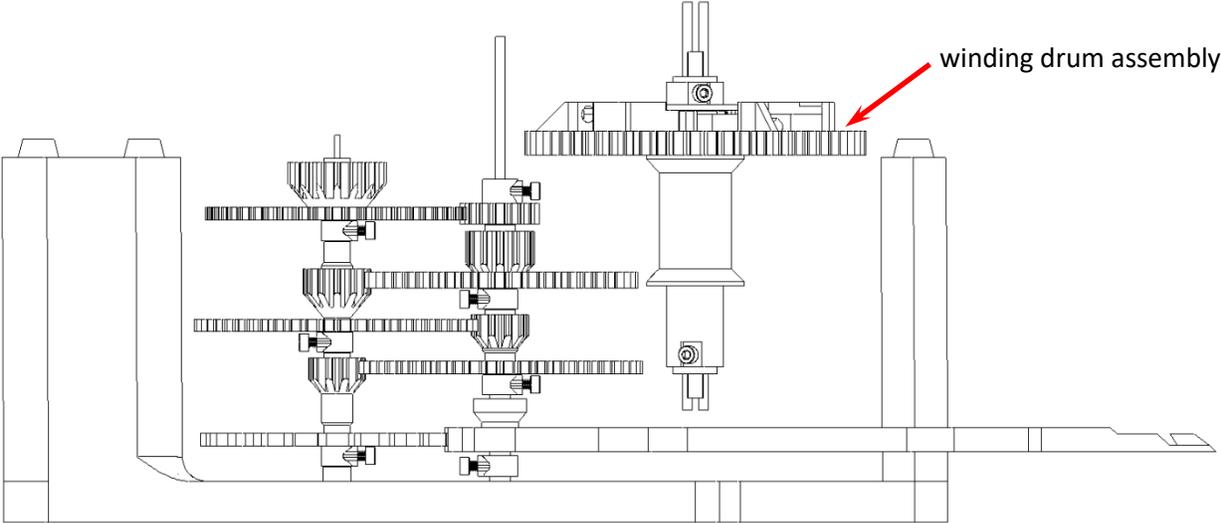
Place both of these arbors into the back frame and add gear 5.



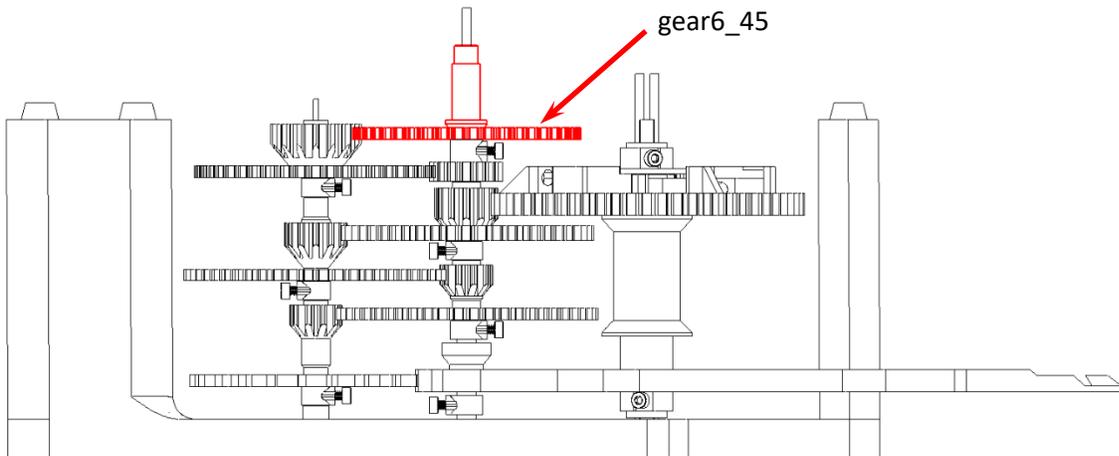
Add one of the large 608 bearings into the back frame.



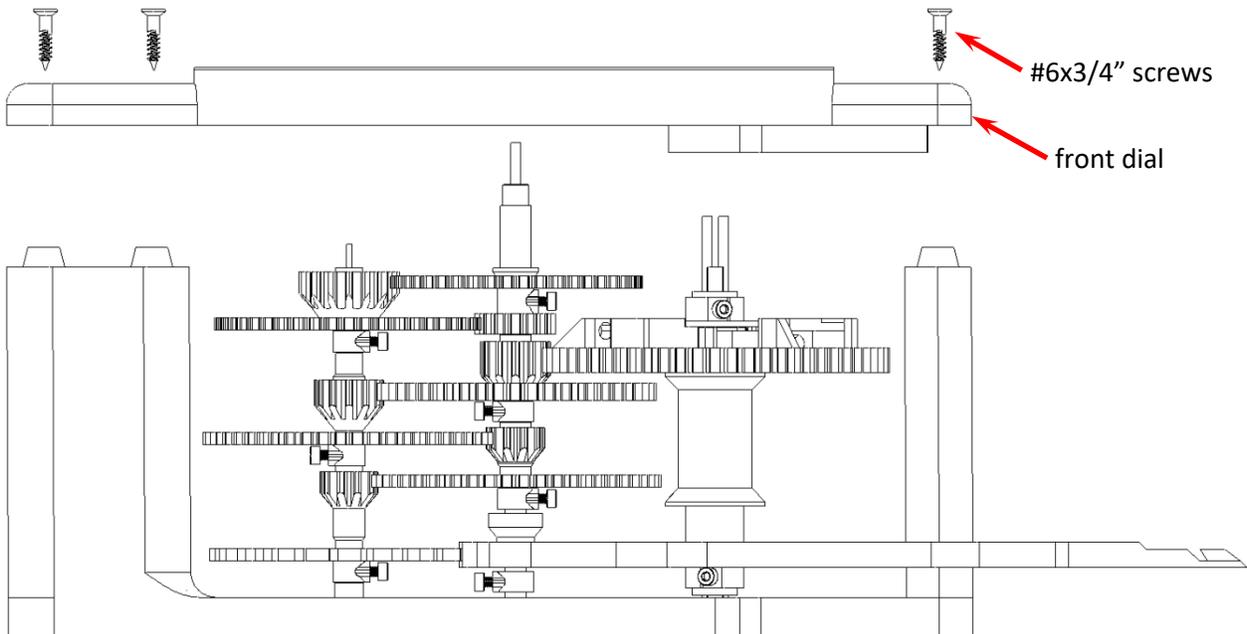
Then add the previously completed winding drum assembly into the 608 bearing.



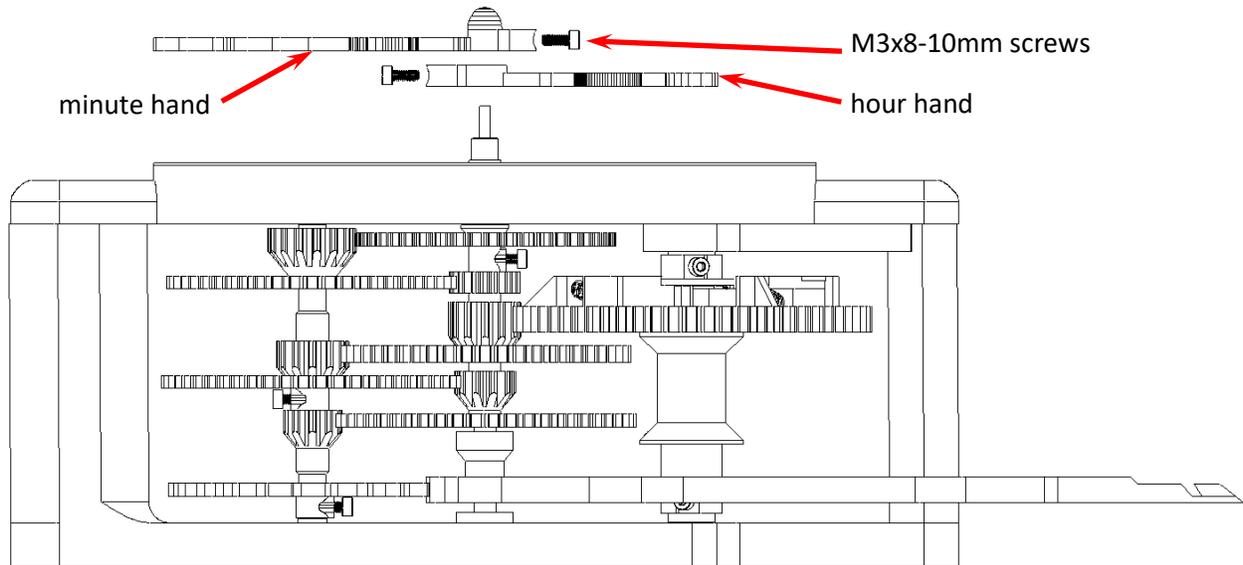
Add gear 6 to the central arbor.



And add the front dial to the clock. Attach it using three #6x3/4" wood screws. The screws are fully visible in this clock, so there are screw\_caps in the misc subdirectory to cover the screw holes if desired. They push in yet are easy to remove if you need to take the clock apart. Leave them out for now, since you may need to take the clock apart several times while debugging.



The last step is to add the hands using two M3x8-10mm screws. Align the hands to a natural position before gently tightening the screws.



Test the friction clutch by moving the minute hand. The hour hand should move accordingly.

## Testing the Clock

The clock mounts on the wall using a single screw driven into a wall stud. I use an #8x1-1/2" or #8x1-1/4" pan head wood screw, but anything that fits securely in the keyhole hanger should work. Placing the screw 68" (1.73m) from the floor will give around 50" (1.27m) of drop for the weights to fall during 7.5 days of run time.

It is very important for the hanging screw depth to be set properly for the clock frame to be supported without sagging. The horizontal support beam at the top of the clock frame is very robust, but the screw needs to be tight against the wall for it to work properly. Adjust the depth for a good fit as the clock is placed over the screw. The internal mounting bracket is tapered so the frame should become tighter against the wall as the clock is lowered to the final position. You should be able to pull down on the front of the clock without seeing any sagging. If there is any sag, the clock hanging screw depth probably needs to be tightened further.

The pendulum on this clock uses simple drop-in components. Add `pendulum_arm_mid` and `pendulum_arm_lower` plus the bob and `pendulum_nuts`.

## Hanging the Weight

Printing the weight shell has been delayed until now so you can determine the exact size needed for your clock to operate properly. My clock will run with a shallow pendulum amplitude using a 4.5lb (2.05kg) weight. It is very robust using a 6.5lb (3.0kg) weight. Your clock may need more or less depending on the overall gear train friction.

Hang various size weights on the line to see how much your clock needs to stay running. An easy method is to use a water jug where you can easily add or take away weight while testing. Start with around 3lb (1.4kg) directly on the line. This amount will later be doubled when the pulley is used. Make sure the frame stays vertical during this test so the clock stays in beat.

Move the pendulum to the side and release it. The escapement tick and tock with each beat of the pendulum. Watch how the escapement moves. It should start to rotate as soon as the pallet tips move past the escapement teeth.

If the escapement is sluggish, it will not add any energy into the pendulum and the clock will quickly stop. Try adding more weight or reduce friction in the gear train until the escapement responds quickly with each tick.

Once everything is working reliably, start reducing the weight to see the minimum amount needed to keep the clock running. We can use this value to determine what size weight shell to print. Take the minimum working amount and double this value to account for the pulley, then add a 50% safety margin, for a total increase of 3X. My clock will run for hours with 2.2lb (1.0kg) directly on the line. Tripling this to 6.5lb (3.0kg) makes the clock extremely reliable.

Tie a loop at the end of the line for the weight. It needs to be able to slip over the small hook near the lower front corner of the clock frame. It is easier to thread the line through the weight shell pulley if the loop is a few inches long. Using a pulley on the weight shell keeps the weight balanced near the center of the clock.

## Weight Shell

The weight shell assembly portion of the manual has been moved to the end with the expectation that you should build the entire clock before you can determine the required drive weight for your clock. The classic clock design books with hundreds of years of experience say there is no way of knowing the exact amount of weight needed. They can give a target range, but there are too many variables and the best way to determine the value is to test it in the completed clock.

The weight is a hollow shell filled with BBs or lead shot to provide energy to run the clock. There are multiple options to create different size weight shells using different densities of fill material.

Copper plated steel BBs have around 80% of the density of lead shot, so a weight shell filled with BBs would only need to be 25% larger than one filled with lead shot to achieve with the same weight. BBs are less toxic and easier to find than lead shot, so it makes sense to use BBs to fill the weight shells. Another option is steel shot ballast used for adding weight to boats. Scuba diving shops may also have ballast material that you can pick up cheaply. Make sure it has the density of steel or copper. Bags of sand will not be dense enough.

This is my new favorite weight shell material from Amazon. The cheapest option is the 50lb bag with enough to build about six clocks. It consists of small BB sized steel balls, essentially BBs without the copper plated shell. They have a slight oil coating, but they are perfectly fine inside the weight shell.



Click image to open expanded view



### Roto Metals Ballast (50 Lb. Weight Filled) Steel Shot for Wakesurf Boats, 50 pounds Weight Bag, Yacht and Airplane Ballast. Made in USA

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Or \$10.83 /mo (6 mo). Select from 3 plans

Or \$10.83/month for 6 months with 0% interest financing on your Prime Store Card

|          |             |
|----------|-------------|
| Size     | 50 pounds   |
| Color    | silver      |
| Material | Metal       |
| Sport    | wakesurfing |
| Brand    | Roto Metals |

BBs can be a cheap option if you only want to build one clock. 6000 BBs weighs around 4.5 pounds (2.0kg), so two containers should be plenty. The price moves around a lot and some brands are 10X more expensive, so shop around. Also make sure to get copper plated steel, not plastic airsoft BBs.



Roll over image to zoom in



### Crosman Copperhead 4.5mm Copper Coated BBs In EZ-Pour Bottle For BB Air Pistols And BB Air Guns

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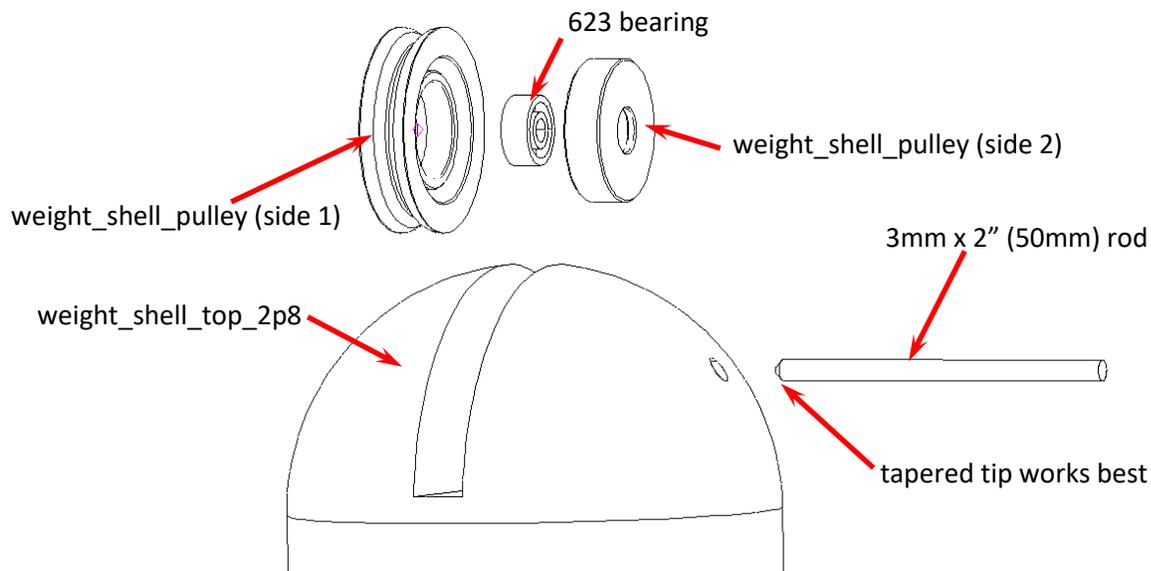
Below is a table showing the approximate weights of various size weight shells. I have built a few of the sizes and extrapolated the rest. The normal height column uses weight\_shell\_top by itself. The weight increase from a single extension is also listed. You can add multiple extensions if needed.

| Weight Shell Diameter | Lead Shot Normal Height | Lead Shot with One Extension | Normal Height Filled with BBs | One Extension Filled with BBs |
|-----------------------|-------------------------|------------------------------|-------------------------------|-------------------------------|
| 2.4"                  | 5.3lb (2.4kg)           | 6.4lb (2.9kg)                | 4.3lb (2.0kg)                 | 5.2lb (2.4kg)                 |
| 2.6"                  | 6.5lb (3.0kg)           | 8.0lb (3.6kg)                | 5.3lb (2.4kg)                 | 6.4lb (2.9kg)                 |
| 2.8"                  | 7.9lb (3.6kg)           | 9.7lb (4.4kg)                | 6.3lb (2.9kg)                 | 7.8lb (3.6kg)                 |
| 3.0"                  | 9.4lb (4.3kg)           | 11.7lb (5.3kg)               | 7.6lb (3.5kg)                 | 9.4lb (4.3kg)                 |
| 3.2"                  | 10.9lb (5.0kg)          | 13.5lb (6.1kg)               | 8.8lb (4.0kg)                 | 10.9lb (5.0kg)                |

Table 6: Approximate weight shell capacities

My clock runs very reliably with the 2.8" shell filled with the steel shot (BBs) shown above.

The weight shell is constructed using a pulley with a small bearing at the top end. The two halves of the pulley enclose the bearing and a pin is pushed in from the side. A tapered tip on the pin helps when lining up with the bearing center hole. The pin is a snug fit. It is OK to drill the hole 90% of the way through so only a small portion is tight. It is also OK to have a loose fit and add a small drop of glue to hold the pin. The pulley should spin freely when assembled.



Turn over the weight shell and fill it with BBs (or lead shot). Take appropriate safety precautions if using lead shot. Assembly should be obvious when you see the parts. The bottom weight shell cover attaches using four #6x3/4" wood screws. Each weight shell extension uses an additional four #6x3/4" wood screws. Multiple extensions can be used if needed.

### Setting the Beat

Move the pendulum slowly to the left and right until it ticks. The clock needs to be adjusted until the left and right sides are balanced. This is called setting the beat. You want the clock to make the sound of "tick.....tock.....tick.....tock....." instead of "tick.tock.....tick.tock.....". Tilt the frame to either side to set the beat. The tall layout of this clock should be close to the proper beat when the frame is vertical.

The clock should tick with a minimum pendulum amplitude of about 3 degrees to either side. The short pallet arms create a very small lever that translates into a large pendulum amplitude. This gives the escapement more time to operate so the clock should be very stable. The minimum amplitude is +/-3 degrees, however the clock becomes more reliable with larger amplitudes. The deadbeat escapement allows the pendulum to swing several degrees above the required minimum. My clock has a swing of about 4-5 degrees on each side for a total amplitude of about 8-10 degrees. Use the swing gauge to measure the pendulum amplitude.

Push the pendulum all the way to one side and release. The clock should continue ticking and the amplitude will reduce to its natural state depending on the drive weight. Additional weight would increase the swing and the clock would be more reliable, although it does get louder.

Set the time by rotating the minute hand.

Congratulations, you have completed your clock!!!

### Adjusting the Rate

The clock should be reasonably accurate with the pendulum nuts near the middle of the adjustment range. Lowering the pendulum bob will make the clock run slower and raising it will make the clock run faster. Every 0.031" change in pendulum length should change the rate of the clock by about a minute per day.

The threads below the bob have around 12.3 threads per inch. One full rotation changes the length by 0.081". This would change the time by about 2.6 minutes per day. It is relatively easy to make small adjustments to get the time accurate to a minute or two per week.

The clock may change its rate during the first week or two as the components settle in to position and everything stabilizes to a consistent rate. Get past this break-in period before attempting the final timing adjustment. My clock is accurate to about a minute per week. I consider this to be pretty amazing.

### Winding

Wind the clock by placing the key in the winding hole and rotate **clockwise**. The winding direction is different than all of my other clocks because the compact design merged the ratchet and winding drum onto a single arbor. This eliminated one gear pair so the winding key sits one stage away from the minute hand instead of two stages away. There is no standard winding direction in traditional clocks. This clock is my first design using a clockwise wind. The ratchet moves easily in the proper direction. Watch the cord to keep it spread across the winding drum instead of piling up in one spot. Sometimes, I guide the line while winding to help distribute the cord evenly.

The clock mounts to the wall on a single screw, so the clock may shift when winding and change the beat. I usually hold the frame steady with one hand while winding to keep it from tilting. You may need to reset the beat after winding if the position shifted.

## Debugging

This clock was designed with the intention of being easy to assemble. Parts are designed to simply fit together and the clock will start working. However, there are hundreds of different printer designs with different tolerances that make each part slightly different. Some adjustment to get the parts to fit properly is expected.

This section of the manual will help guide you through some additional debug steps if your clock does not start working right away.

The pre-check summary is repeated to emphasize the importance of these steps. They are all related to reducing friction. Going through this list again will give your clock a good head start.

- 1) Visually inspect the gears for defects like elephant foot or excess stringing
- 2) All gears spin on their arbors
- 3) All arbors spin in the frame arbor holes
- 4) Gear 6 fits through the front dial and spins easily
- 5) Pendulum bearing free swing test runs for at least 10 minutes, preferably closer to 20 minutes
- 6) All arbors have some end shake inside the frame

A few additional checks can be added after the clock is assembled. It is important to notice how the clock is stopping to decide where to focus your debug efforts.

- 7) Is the clock hanging properly to minimize frame sag?  
The first thing to check is if the clock is hanging properly. If the clock is simply hung on a nail, the main support beam can tilt downwards from the weight on the front of the clock. This will cause the thin sections of the frame to bend so the entire frame becomes a parallelogram and the gears can go out of alignment. They could become pinched by the frame. Or the gears could tilt so the sidewalls interfere. The hanging screw depth needs to be properly adjusted and it needs to be strong enough so it will not pull away from the wall.
- 8) Is the clock in beat? Move the pendulum slowly from side to side to observe.  
A clock that is in beat will have a balanced tick tock sound as the pendulum moves back and forth. This clock should be close to being in beat with the frame vertical. The only adjustment is to tilt the frame left or right. Only a small amount of adjustment should be necessary. It is a good idea to check the beat after each winding since the frame might have shifted. A clock that was previously working great but stops running within a few minutes of winding is often an indication that the beat was changed while winding.
- 9) Does the escapement rotate quickly when the pallet arms clear the escapement teeth?  
This clock has a Graham deadbeat escapement that allows the pendulum to swing freely to its natural amplitude without pushing the escapement backwards. The escapement needs to rotate quickly when it changes from the “dead” portion to the active portion where the angled teeth engage and the escapement pushes on the pendulum. If the escapement is really sluggish, it will not impart any energy into the pendulum and the clock will quickly stop.  
If the escapement starts spinning slowly, it might barely touch the pallet arms before the pallet moves past. Some energy is transferred, but not the full amount. The clock may run, but the

pendulum amplitude will be weak. The problem could be friction in the gear train or too small of a drive weight. The friction pre-checks may help. You could also try a small bit of grease on the pinion teeth. PLA seems perfectly tolerant of most lubricants. Adding extra drive weight may help, but avoid adding significantly more than the target of around 6.5 pounds (3kg).

10) Does the pendulum slowly lose amplitude and eventually stop?

This could either be too much pendulum support bearing friction or not enough drive weight. Some builders mention that they get less than a minute on the pendulum free-swing test. I have not found a 623 bearing that runs for less than 5 minutes unless the bearing felt like it was dropped in sand. I have ordered hundreds of bearings and never see more than 1-2% that are bad. And I buy the cheapest bearings I can find. The bearings usually come in sets of 5 or 10. Try different bearings from your set if needed.

Another thing to check is if the bearings are really tight in the frame, they might be skewed and adding a side load which will cause extra friction. Enlarge the hole slightly so the bearings are loose but not sloppy in the frame.

If all the pre-check friction tests are working, then try adding a weight shell extension.

11) Does the clock stop in less than a minute?

If the pendulum free-swing test runs for 10 minutes, then the clock should run for several minutes unless the escapement is getting in the way of the pallet. You may see the escapement jump from the pallet arms hitting it. This may be caused by friction in the gear train not allowing the escapement to rotate quickly. Repeat the pre-check tests looking for where the excess friction is coming from.

12) What is the pendulum amplitude?

The minimum pendulum amplitude for the clock to run is three degrees in each direction, however a clock with only three degrees of swing will stop from the slightest disturbance. Four or five degrees in each direction will be much more stable. Try reducing friction or adding more weight to get closer to the 4-5 degree target.

13) Does the clock appear to run, but the time does not change?

This is usually a simple fix to reduce friction in the hour hand gears. The friction clutch in this clock provides a very tiny clamping force around the arbor. Gear 6 passing through the dial needs to have less friction than the friction clutch provides. If gear 6 is binding, then the friction clutch will slip and the time will not change. Sand the gear 6 shaft or the frame opening where gear 6 passes through. Or it could be caused by a lack of end shake on the central arbor. Reduce the height of one of the gears in the stack or the spacers making up the friction clutch. The good news is that the primary gear train is working so the clock is almost completely functional.

14) Look at the clock from the side. Are any gear side walls touching?

The clock is designed with a reasonable amount of clearance between gears that are not supposed to touch. It is a balance between just enough clearance to make a compact clock or a lot of clearance making a really large clock. Possible causes include frame sag, warped gears, or too much end shake allowing extra sideways movement. Frame sag is usually fixed by tightening

the mounting screw. Warped gears may need to be re-printed. Excess end shake can be solved by adding spacers to limit the sideways movement.

15) If all else fails, test gear pairs looking for excess friction.

Most of the pre-check tests focus on individual components or small modules. Sometimes, the extra friction occurs when gears don't mesh properly. Try testing gear pairs and spin them by hand. For example, put just gears 3 and 4 into the clock. Do they spin easily? You may need the spacers or other gears above gears 3 and 4 so you can add the front frame to hold the arbors straight. Try again with gears 2 and 3. Keep going through the gear train testing pairs.

16) Test the entire gear train without the pallet.

After testing all the gear pairs, try the entire set of gears without the pallet. A spacer may be needed to account for the space taken up by the pallet. Hang the clock on the wall. Add the weight shell. All the gears and the escapement should spin. It may take an hour for the weight to reach the floor. This is also a great way to break in the clock.

If the gears stop, look for friction where they stop. Touch each gear. If it starts spinning, see if you can find anything near that gear causing friction. Start and stop the escapement. It should start spinning quickly each time.

17) Make sure the pendulum bob is not touching the wall.

The pendulum swings almost a million times in 8 days. There is not enough drive weight to make up for the pendulum to scrape the wall a million times. Gently bend the pendulum arms to guide the bob away from the wall if needed.

18) Check that the weight cord is not tangled.

The weight cord can sometimes bury into a pile and get pinched. Shift the cord position to let the clock continue running. And gently guide the cord to use the entire drum when winding.

These are some of the most common reasons why your clock might not be working right away. A mechanical clock is a complex piece of engineering, so there may be other reasons. I try to design using loose tolerances, but there can still be things that need adjustment for your clock to function properly.

Once the clock is working properly, it should continue to work for many years. I have been running mine for a few weeks so far and it has been working flawlessly. My other clocks with similar construction techniques have been running for years. The large pendulum amplitude in this clock should make it a very reliable design. I believe that this should be my easiest to build and most reliable design.

You can ask questions on MyMiniFactory or the forum at <https://www.stevesclocks.com/groups> Try to provide as much information as possible. Mention how much weight you are using. Describe the escapement characteristics, especially just after the clock stops. Move the pendulum back and forth to observe how quickly the escapement responds. Double check that the clock is in beat. The pendulum free-swing time for your clock is also useful information.

You can post pictures of your clock on any of the web sites. The forum allows any type of clock related questions and comments, even related to clock designs from other designers.

## Final Comments

Clock design has been a hobby of mine for many years. It really expanded about five years ago when I got my first 3D printer. The ability to quickly go from prototype to working clock is so easy with a 3D printer. I usually have several works in progress at any time. Some are grand plans that may take years to complete. Others are minor revisions.

The design of this clock started well over 10 years ago when I planned the tower of 50, 48, and 45 tooth gears. It took a 3D printer and several years of clock design experience to make it into a functional clock. Many new innovations were needed to fit everything into a compact design. The friction clutch is a new design. Integrating the ratchet into the winding drum is also new. The compact design reduced the frame to just a few pieces. The short distance between the pallet and escapement translates into a large pendulum amplitude that should be very reliable.

In addition to all these new innovations, many other design features carry over from my other clock designs. The “perfect print gears” have been proven to work great in a 3D printed clock. The dial is similar to all of my other clocks. There was no need to redesign the weight shell. Using small ball bearings to support the pendulum has been proven to be a robust design. It should be even better in this clock since the pendulum bearings are slowly rotated by the minute hand arbor. This should reduce the risk of the bearings moving back and forth between the same two positions.

All these things combined make this my smallest and easiest to build pendulum clock. All of the gears are still highly visible. My older clocks focus on the escapement that was always large and towards the front. This clock focuses more on the pendulum which is more energetic and no longer hidden behind the frame. It is a different design style compared to my other clocks. I believe that the design will make this become my most reliable clock.

This clock has been released on MyMiniFactory. Feel free to check out my other clocks. They are easy to find by searching for “Steve Peterson clocks”. You can find additional information on my web site at <https://www.stevesclocks.com>

Parts kits for all the non-printed parts except the weights will be available on my Etsy store. Check the main description on MyMiniFactory for a link. The simple parts list should make the kit very reasonably priced.

I have been experimenting with wooden gears in an attempt to make a wooden gear clock, but have not yet completed a fully functional weight driven pendulum clock. One of my goals is to shift my clock design efforts into wooden clocks. I actually started trying to build a wooden clock, but switched to printed clocks as soon as I received my MK3 printer. The 3D printer makes it so easy to build prototypes and I have released over a dozen designs so far. I may have a few more printed designs in progress, but I hope to get back into the workshop to start making a wooden gear clock soon. Stay tuned for more information.

Good luck with your clock build.

Steve

I often display my clocks at local Maker Faires. It is always a great experience. Many visitors seem to be interested in the large robots, but I usually have constant stream of visitors in the clock booth. It is refreshing to see so many young people asking how to design a clock. Here are some of the wall mounted clocks.



And the desktop clocks.

