

Paul Trap Creation Manual

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1 shielding box

Trapped particles may escape due to the influence of wind. To prevent this, a box is created to shield against the wind.

Parts List

- `shielding_box.stl`¹

- `window.stl`

- M3 screw

Secure them with screws as illustrated in the photo (Fig. 1). Please be aware that the tap has not been cut for the hole in this model (the hole diameter itself is $\phi = 3$ mm).

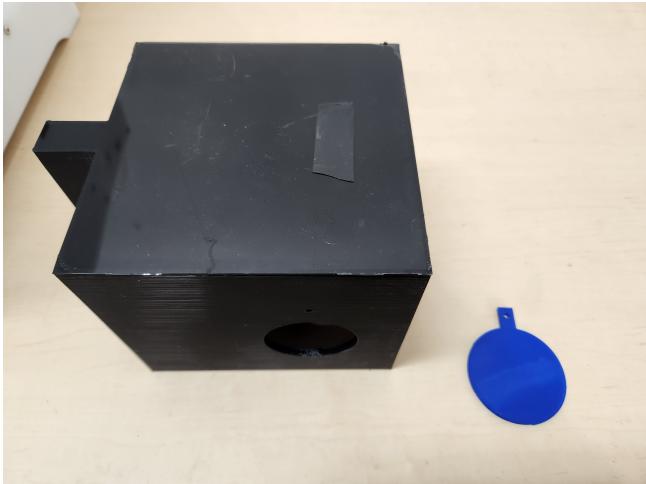


Figure 1: (left) `shielding_box.stl` and `window.stl`, (right) assembled product

¹If the filament used to print "`shielding_box.stl`" is not black, there may be insufficient light shielding, making observation difficult. In such cases, it is recommended to apply black paint on the inside.

2 power supply module

Parts List

- power_supply_module_box.stl
- power_supply_module_box_lid.stl
- Toggle switch (S-21A, NKK switches)
- High-voltage transformer² (UFO-6K-001-P100, UNION ELECTRIC)
- Power cable
- Two banana plugs

1. Solder banana plugs to the output side of the transformer (Fig. 2 left).
2. Solder the high-voltage transformer, toggle switch, and power cable as shown in the photo (Fig. 2 center).
3. Attach the toggle switch to the power_supply_module_box.stl, insert the transformer, and secure it with screws (Fig. 3). While screws are not necessary, securing them with screws and nuts is advisable to prevent misalignment. Depending on the print quality, installation may be slightly challenging.
4. Finally, cover it with the lid to complete the assembly.

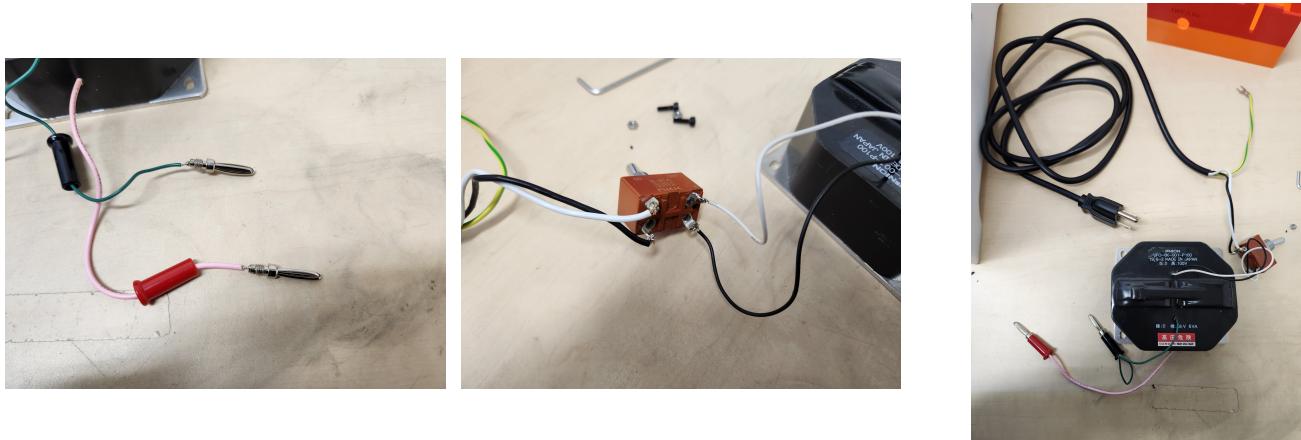


Figure 2: (left) soldering banana plugs, (center) soldering toggle switch (right) the finished product after soldering

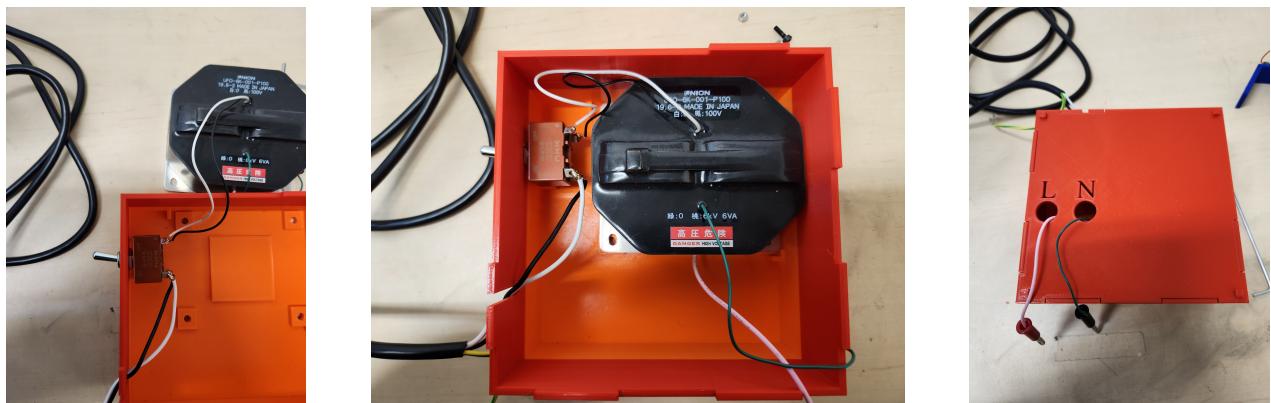


Figure 3: (left) attach the toggle switch to the power_supply_module_box.stl, (center) insert the transformer (right) assembled product

²The high-voltage transformer is designed for an input voltage of AC 50/60Hz, ranging from 0-100 V, and it amplifies this voltage by a factor of 60.

3 ring-type electrode module

Electrode section

- `ring_electrode.stl`
- `endcap.stl`
- `electrode_holder.stl`
- Conductive paint (SKU-0216, BARE CONDUCTIVE)
- M3 Low-profile screw (4 mm)
- Crimp terminal
- Jumper wire
- M4 Screw (10 mm). Recommended hex socket screw

LED section

- `LED_holder.stl`
- LED
- Breadboard
- Jumper wire
- 9 V battery
- Toggle switch (448-0753, RS PRO)
- Battery Strap (489-021, RS PRO)
- Resistor
- M4 Screw (10 mm). Recommended hex socket screw

Web camera section

- `camera_jig.stl`
- Web camera (USB130W01MT-MF40-J)
- 1/4-inch screw

Main body section

- `ring_trap_box.stl`
- `ring_trap_box_lid.stl`
- Two banana sockets (23.3020-21, Staubli)
- Two 10 MΩ resistors (HB110MFZRE, TE Connectivity)
- Crimp terminal

3.1 Ring electrode

1. Apply conductive paint to `ring_electrode.stl` and `endcap.stl`, and let it dry (Fig. 4).
 - Consider multiple coats if adhesion is poor.
 - Note: Conductive paint is not suitable for long-term storage; proper storage is crucial to prevent drying. Adding a small amount of water can revive it, but the quality may be compromised.
2. Prepare jumper wires with crimp terminals on both ends.
3. Connect one end to the electrode using a low-profile screw (Fig. 4).
 - Be mindful of wire orientation.
4. Attach the electrode to `electrode_holder.stl`, aligning as shown Fig. 5.
5. Secure with screws
 - Not all holes need to be used.
 - Hex screws are recommended because the holes haven't been fully tapped, so the screw is tight.

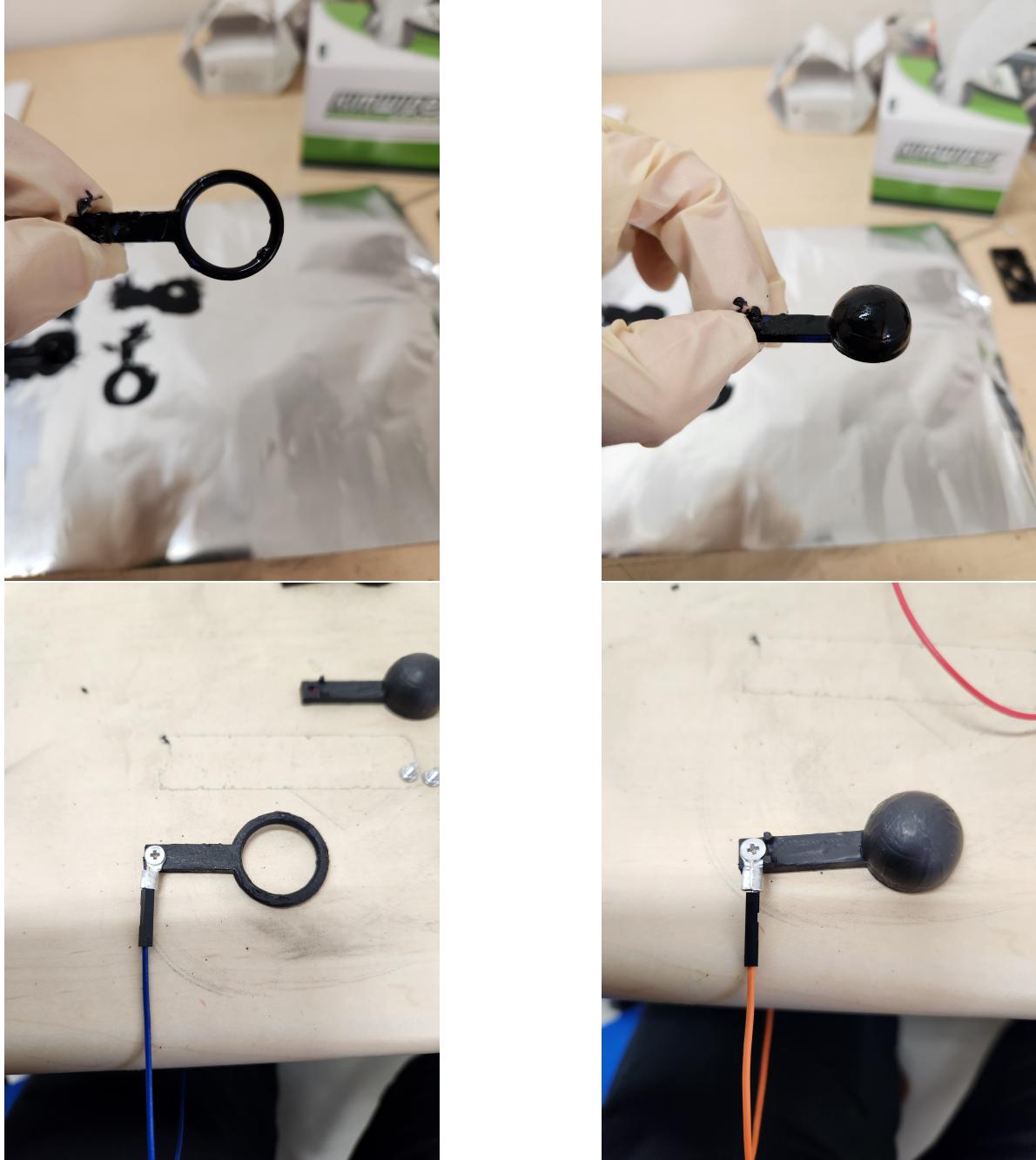


Figure 4: (left) ring electrode, (right) endcap

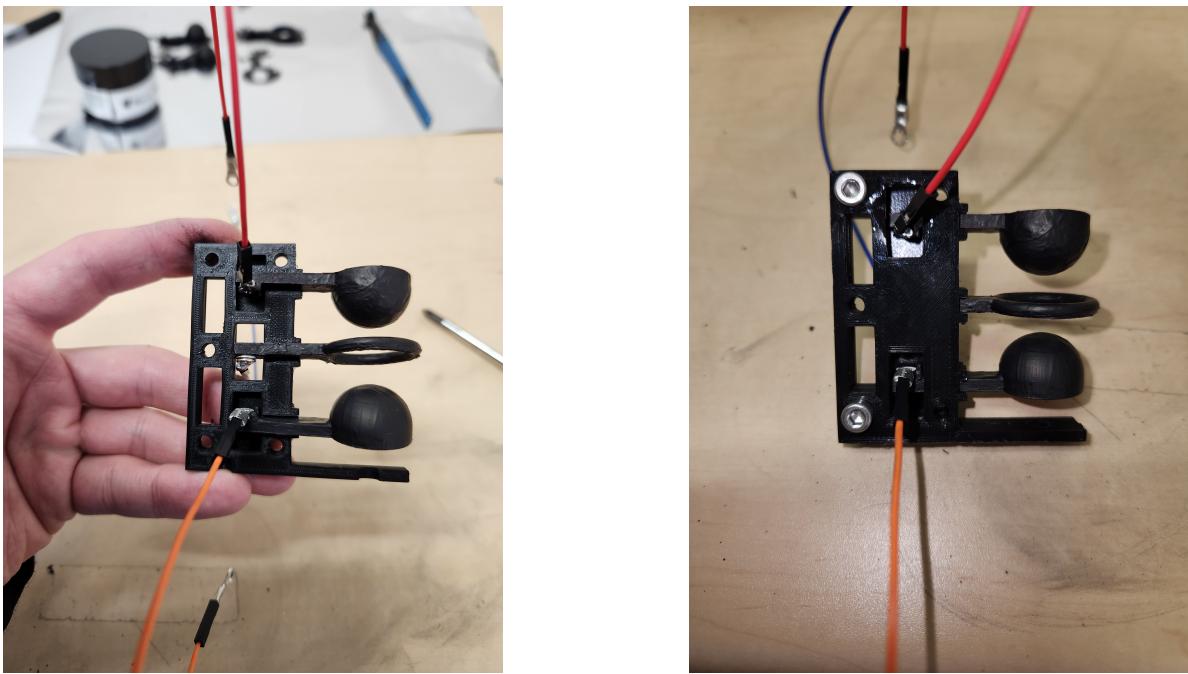


Figure 5: (left) attach the electrode to `electrode_holder.stl`, (right) securing with screws

3.2 LED circuit

If you can create a circuit that illuminates an LED, any circuit is acceptable. A brighter LED enhances visibility, and a blue-toned color is recommended. However, please note that we use the toggle switch (448-0753, RS PRO), and there is a side opening for its installation. Additionally, for the jumper wire connecting to the LED, having a longer length makes installation easier.

Figure 6 represents an example of an actual circuit in use.

Note: `LED_holder.stl` will be attached after installing the cover, as explained later.

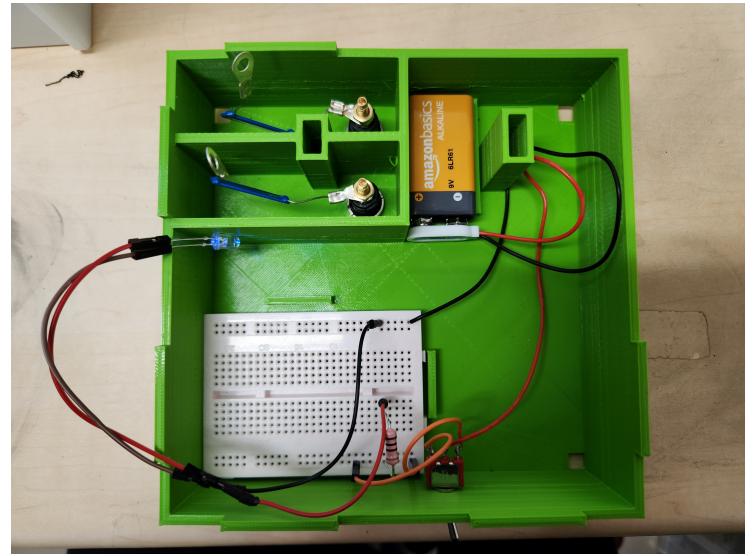
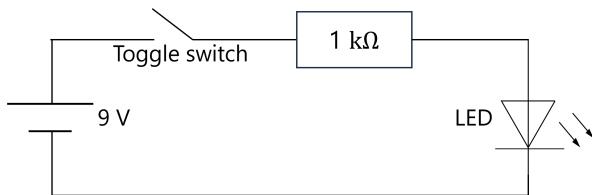


Figure 6: An example of LED circuit.

3.3 Web camera and Main body

1. Attach the banana sockets to `ring_trap_box.stl` (Fig. 7 left). The limited space may make installation challenging, so use tools like needle-nose pliers to assist in securing.

2. For safety, install a $10\text{ M}\Omega$ resistor between the high-voltage transformer and the electrodes (Fig. 7 left). Attach crimp terminals to both ends of the resistor, securing one end to the banana socket with a screw. While this setup is generally sufficient, be aware of potential metal fatigue leading to foot breakage. Improvements may be considered in the future.
3. Place the previously mentioned LED circuit inside the box and attach the toggle switch to the side hole (Fig. 7 center).
4. Cover with `ring_trap_box_lid.stl`. Ensure the LED and electrode terminals protrude through the holes in the lid (Fig. 7 right).
5. Install the web camera fixture as shown in the figure and set it on the lid (Fig. 8 top panel).
6. Fix the LED in place with tape, secure it in the holder, and fasten with screws, preferably hex screws as recommended (because the holes haven't been fully tapped, so the screw is tight).
7. Insert the completed electrode and LED stand into the slots. Since they are intentionally made snug for stability, firm pressure is required for insertion (Fig. 8 middle panel).
8. Connect the electrodes (ring electrode and two endcaps) to the terminals of resistors. The assembly is complete (Fig. 8 bottom panel).
9. In this configuration, the electrode gap is designed to operate within a voltage range of 0 to 6000 V. For safety reasons, please refrain from applying voltages exceeding 6000 V.

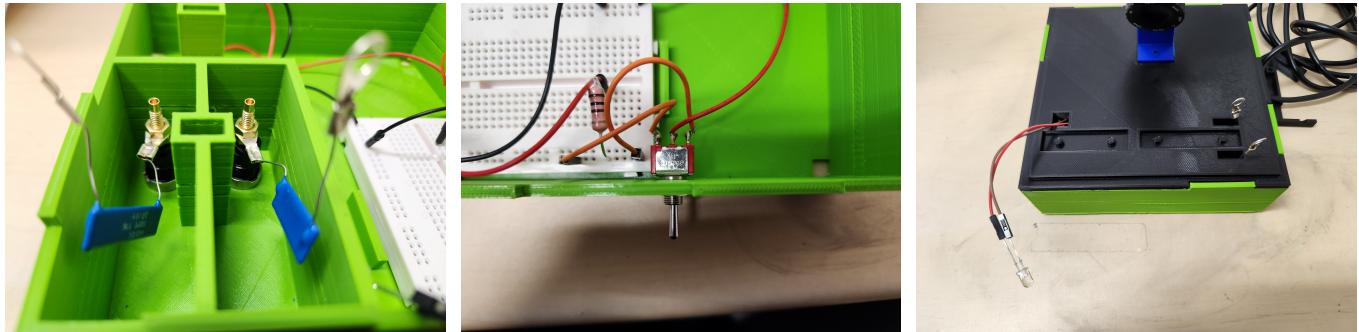


Figure 7: (left) attach the banana sockets to `ring_trap_box.stl`, (center) attach the toggle switch to the side hole, (right) extend the terminals of the LED and electrode through the holes in the lid

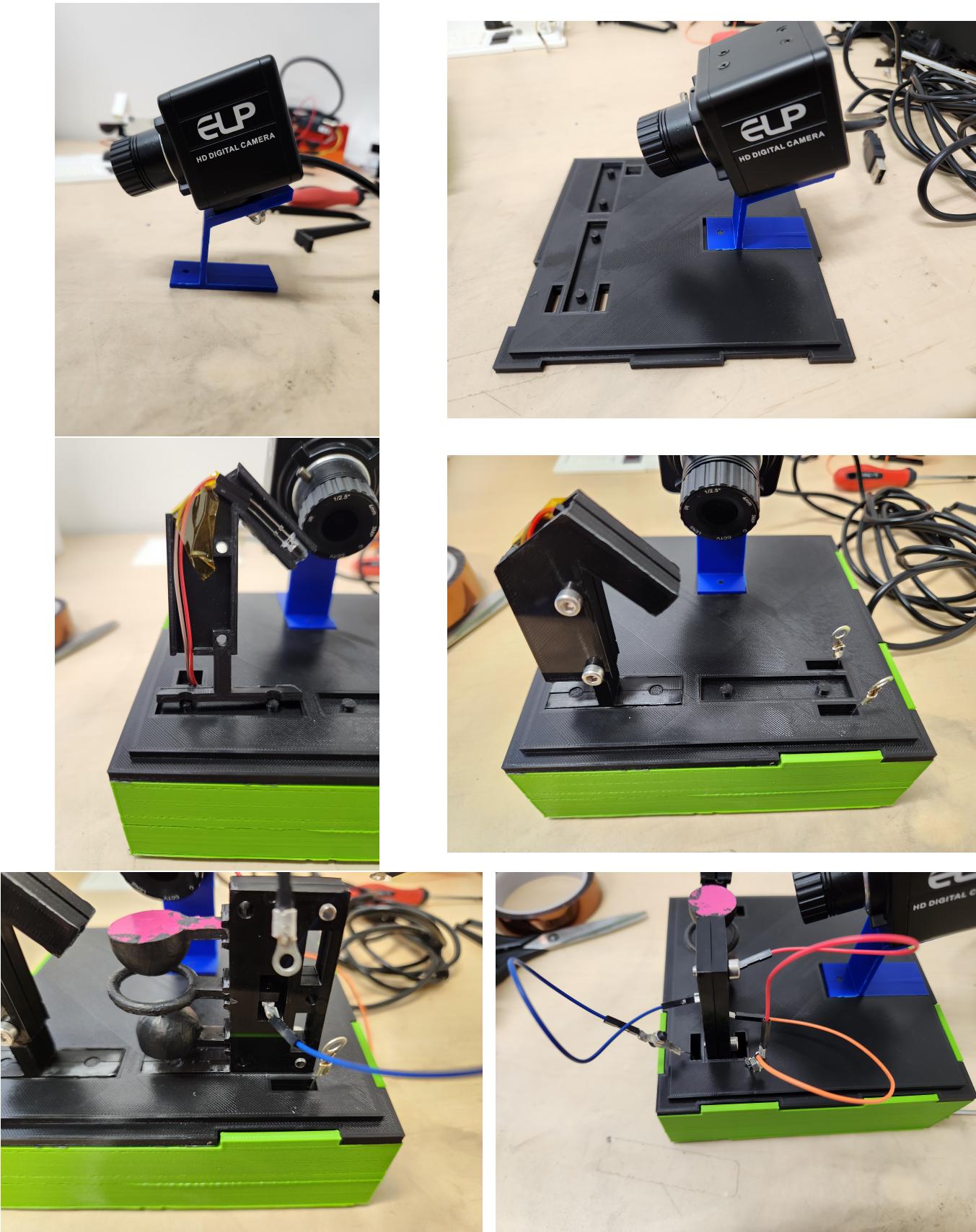


Figure 8: (top panel) web camera and `camera_jig.stl`, (middle panel) LED holder, (bottom panel) connect the electrodes to the terminals of resistors

4 Linear type electrode module

The linear type design has not been refined yet, but we intend to improve it in the future.

After adding components (ruler and jig) for image analysis, the web camera (C920n, Logicool) was external, and the shielding box did not fit, so we used a large acrylic box as a substitute. LED was not suitable due to slight light diffusion issues, hence a laser pointer was employed. It was temporarily placed on top of the acrylic box, as illuminating from directly above proved effective. Our future plan involves integrating these components into an all-in-one product.

To trap particles strongly in the xy-direction, we narrowed the distance between electrodes. Consequently, the maximum applied voltage was set lower than that of the ring electrodes (up to around 2100 V). We recommend using it in conjunction with a variable transformer and inputting lower voltage (around 35 V) to the high-voltage transformer.

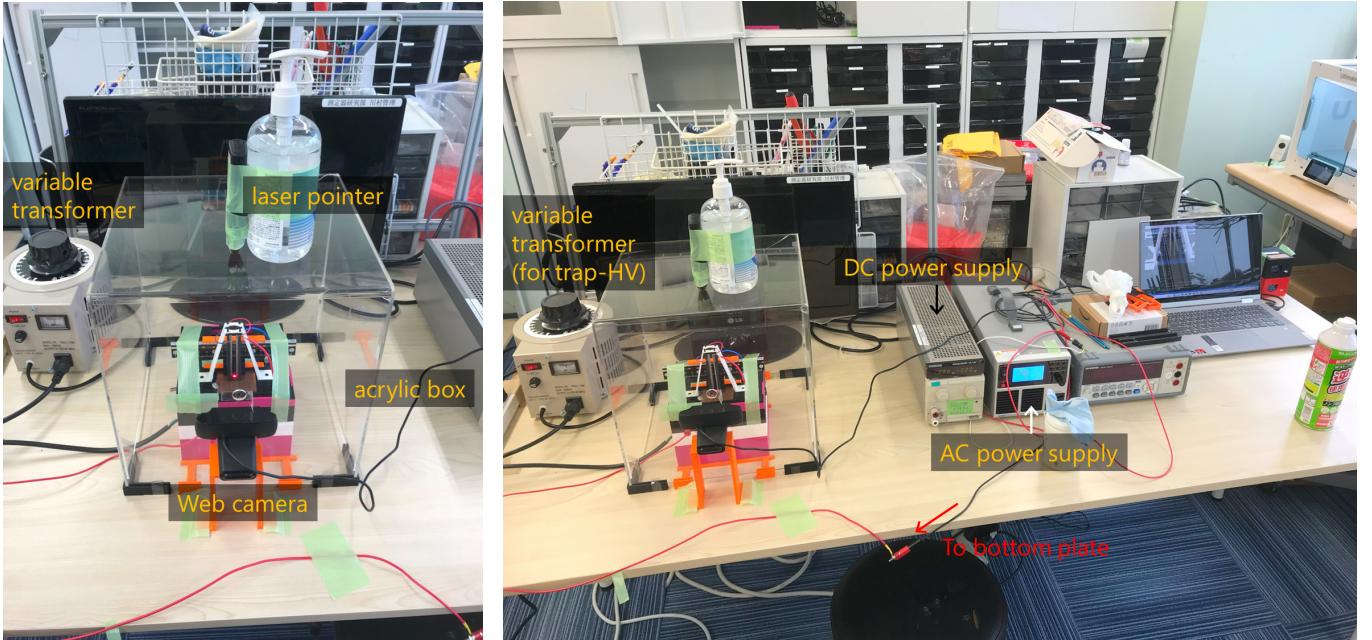


Figure 9: (left) the overview of the device, (right) the overview of the experimental setup.

Electrode section

- electrode_jig1.stl
- electrode_jig2.stl
- electrode_jig_stopper.stl × 2
- Four metal rods ($\phi = 3$ mm, $L \approx 75$ mm)
- Wire
- Crimp terminal

Bottom plate section

- metal plate (around 55×55 mm², thickness = 3 mm)

Main body section

- linear_trap_box.stl
- linear_trap_box_lid.stl
- ruler_jig.stl
- Three banana sockets (23.3020-21, Staubli)
- Two 10 MΩ resistors (HB110MFZRE, TE Connectivity)
- Crimp terminal

4.1 Linear electrode

1. Insert four metal rods into `electrode_jig1.stl`.
2. Mount `electrode_jig2.stl` on top and secure the rods in place (Fig. 10 top right).
3. Wind wires around the rods ((Fig. 10 top left)) to enable voltage application³. Attach crimp terminals to one side of the wire. Connect each pair of electrodes placed diagonally to create a quadrupole electric field. To prevent discharge, route the wiring on the outside, and consider using insulating materials like Kapton tape.
4. Insert two `electrode_jig_stopper.stl` from above to fix them to the main body (Fig. 10 bottom left).

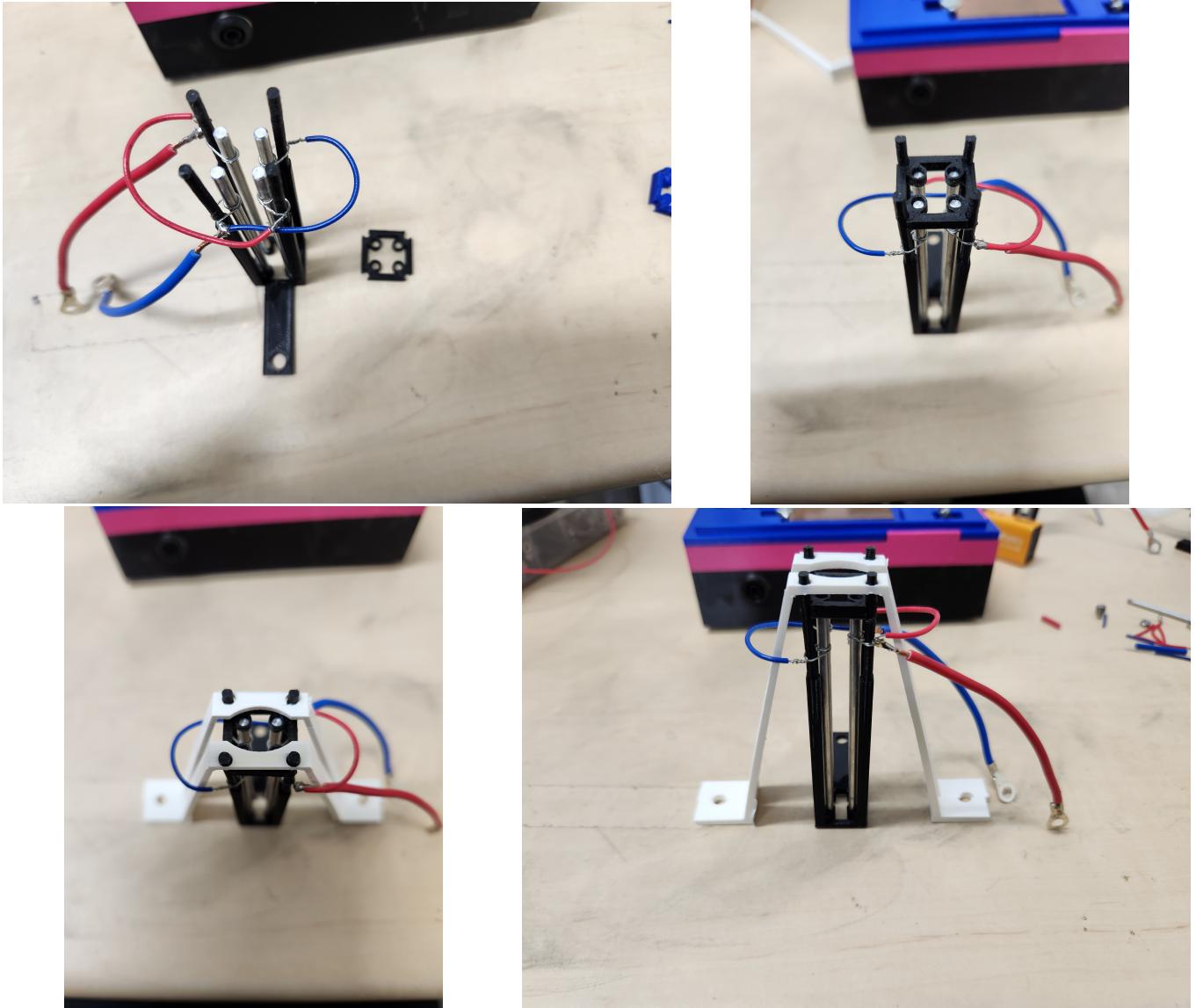


Figure 10: (top left) insert four metal rods into `electrode_jig1.stl`, and wind wires around the rods, (top right) mount `electrode_jig2.stl` on top, (bottom left) insert two `electrode_jig_stopper.stl`, (bottom right) the overview of the linear electrode

4.2 bottom plate

The material of the metal plate can be any as long as voltage can be applied. To wire the metal plate, fix screws. If there are holes at the edge of the metal plate, it's easy. However, if there are no holes, soldering or other methods can

³Since it might be difficult to wire after attaching the metal rods, it may be better to connect the wires first and then insert the rods.

be used to attach the screws forcefully (Fig. 11).



Figure 11: (left) soldering a screw to a bottom plate, (center) thickness of the plate, (right) width of the plate

4.3 Main body

1. Attach banana sockets to `linear_trap_box.stl`. Connect two for the power supply module and one for applying voltage to the bottom plate (Fig. 12). There is an extra hole on the box, but it won't be used this time.
2. Attach $10 \text{ M}\Omega$ resistors to the power supply module side banana sockets, similar to the ring-type configuration (Fig. 12 center).
3. Attach a wire with crimp terminals to the banana socket on the bottom plate side, allowing connection to the plate (Fig. 12 right).
4. Place the metal plate in the groove of `linear_trap_box_lid.stl`. Then, attach it to `linear_trap_box.stl`. At this time, connect the terminal and the bottom plate (Fig. 13).
5. Attach the electrode created earlier. When inserting `electrode_jig_stopper.stl` into the slot of `linear_trap_box_lid.stl` it might be a bit difficult (because it's made slightly tighter for better fixation) (Fig. 14).
6. Connect the terminals of the resistors to the wire of electrodes with screws and nuts (Fig. 14 right).
7. If setting up a ruler for image analysis, insert the ruler into `ruler_jig.stl` and attach it to the main body (Fig. 15 left).



Figure 12: (left) Attach banana sockets to `linear_trap_box.stl`, (center) the power supply module side, (right) the bottom plate side

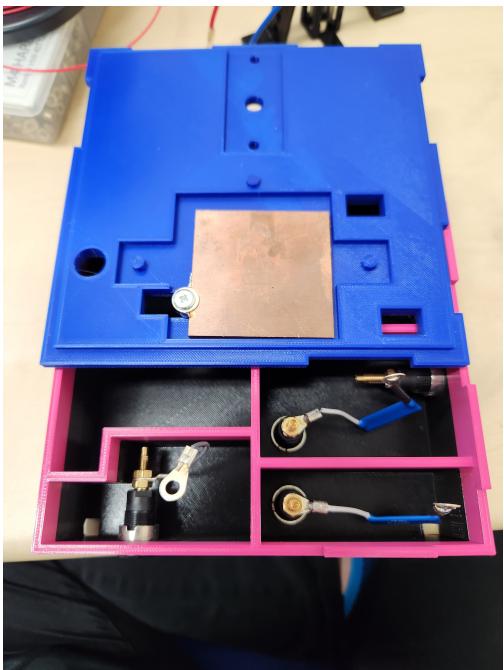


Figure 13: (left) place the metal plate in the groove of `linear_trap_box_lid.stl`, (right) connect the terminal and the bottom plate

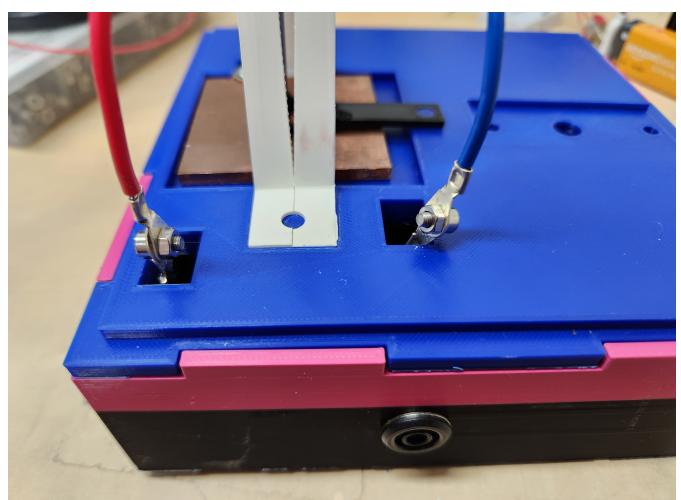
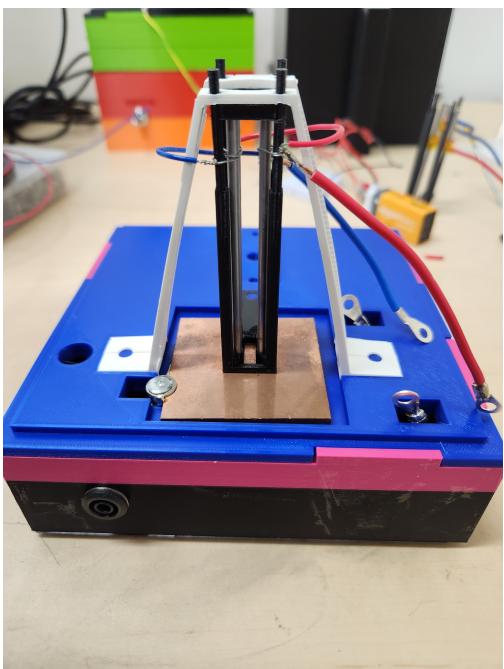


Figure 14: (left) attach the electrode, (right) connect the terminals of the resistors to the wire of electrodes with screws and nuts

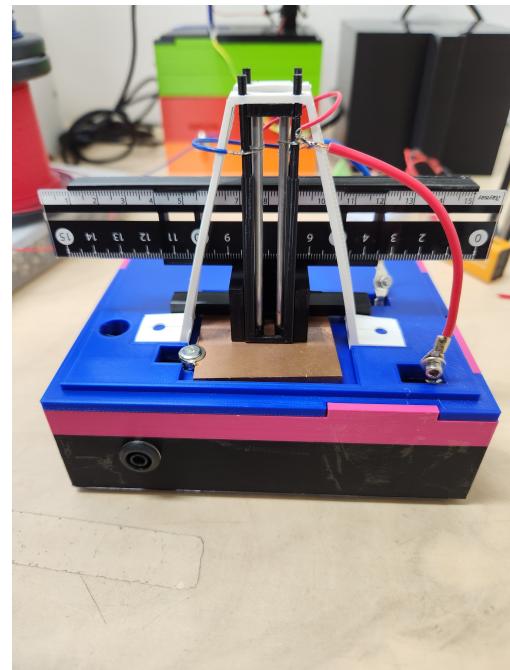


Figure 15: (left) a ruler and a jig, (right) overview of the linear electrode module