

## *Newtonian Labs*

# - Do It Yourself Ion Trapping - How to Construct a Microparticle Ion Trap

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Building your own ion trapping experiment from Newtonian Labs. Here is a quick do-it-yourself guide you can use to construct your own inexpensive microparticle ion trap.

Step 1: Read the paper: *“Improved Microparticle Electrodynamic Ion Traps for Physics Teaching,”* by Kenneth G. Libbrecht and Eric D. Black, available at <http://newtonianlabs.com>.

This paper explains the physics of microparticle electrodynamic ion traps (MEITs) and describes some of the experimental “tricks” that make trapping easier.

Step 2: Find a source of high voltage. Ideally you want 6kV AC at 50-60 Hz. High-voltage transformers that put out 6kV are not so easy to find, unfortunately. You can find one source at <http://newtonianlabs.com>.

Voltages as low as 2-3 kV will trap, but 6kV works a lot better. An old neon-sign transformer might do the job, but not one of the modern solid-state power supplies (these run at high frequencies, far above 50-60 Hz). To make a MEIT, you need an old-fashioned transformer, with coils of actual wire.

Step 3: Buy some proper current-limiting resistors. We suggest 10 M-Ohm, 10 Watt resistors, as these keep currents below 1 mA. (See a suggested circuit below.) With proper current limits (see the paper in #1 above), ion traps are harmless. Without current limits, you

might just manage to kill yourself. Also, box up the transformer and current-limiting resistors using a grounded chassis.

Step 4: Buy some Lycopodium club-moss spores. These are basically pollen particles, about 25 microns in diameter. They are cheap (about \$10 for a small vial), easy to buy (search for “Dragon’s Breath” online), harmless, and they trap well.

Step 5: Get some kind of laser to illuminate the trapped particles. Trapped particles are so dim in room lights that most people will not see them in a trap.

Step 6: Put your trap together. We recommend a single-electrode ring geometry, as this makes a simple trap that is easy to see.

Step 7: Charge the particles using a Teflon “wand”. Without charge, the particles will fall right through the trap. Charge up the tip of a Teflon stick by rubbing it with a piece of cloth, then use it to pick up some particles. Shake the particles off the stick and into the trap.

Step 8: Mind the air currents. You can trap particles in a quiet room, but a small puff of air is usually enough to blow particles out of the trap. Better to put a box around the trap, with holes or windows for loading and viewing.

Step 9: Improve your design. If you want a MEIT that makes traps like the ones shown below, that

takes a bit of effort. If you want nice traps without the work, buy a full EIT experiment from Newtonian Labs!

### Additional Information

#### **Safety Notes**

Working with high voltages, you should be concerned about safety. The main thing to remember is that high voltage is only hazardous in combination with high currents.

There is an old saying among electrical engineers – *it's the volts that jolts, but it's the mills that kills*. In other words, what matters is not so much the voltage alone, but rather the current it can deliver to your body.

As a rule of thumb, 1 mA of continuous current is about at the limit of what you can detect. If you grab onto a high-voltage wire and it delivers a 1 mA current, then you will feel at most a slight tingle. Moving up, 10 mA will give you a respectable shock, and 100 mA could be lethal.

If you experience a quick electric shock instead of a steady current, then an important number is the energy it delivers. A defibrillator typically delivers a few hundred joules, for example, so that gives you an idea how much energy is involved in a heart-stopping shock. At the other end of the spectrum, the shock you get from rubbing your shoes on a carpet is likely a tenth of a Joule or less.

The energy in a sudden shock usually comes from the discharge of a capacitor. In this case the energy delivered is at most  $CV^2/2$ , where C is the capacitance being discharged and V is the voltage.

Now let's look at building a MEIT. The transformer can deliver 6kV, and by itself it has no current limit. This high a voltage could drive harmful or even lethal currents into your body.

To address this, we add a 10 M $\Omega$  resistor to the output, which limits the current to 6 kV/10 M $\Omega$ , which is less than 1 mA. This makes the MEIT quite safe – *as long as the current limit is in place*. We usually add two 10 M $\Omega$  resistors, for redundancy, as explained below.

Next let's look at the energy in a possible electric shock. If you just have a ring electrode attached to the transformer output (see below), then the capacitance of the circuit is small, probably around 10 pF or less. This means the shock energy will be at most  $CV^2/2 < 1$  milli-Joule, which is negligible.

#### Parts List

Here is a suggested list for making your own MEIT:

One 6 kV transformer. (These are not so easy to find; we sell one at <http://newtonianlabs.com>)

Two 10 M $\Omega$ , 10-Watt resistors. (Get these from Mouser, Digikey, or your favorite electronic supplier)

An Electronics Chassis (basically a metal box)

Copper Ring (a loop of wire will do)

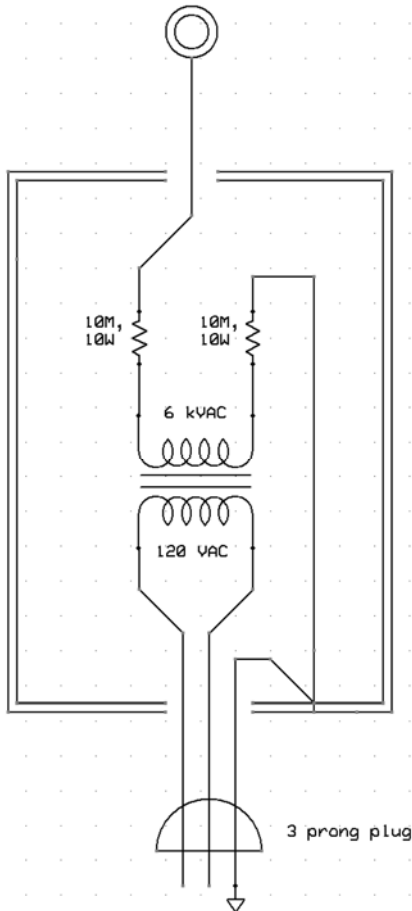
Lycopodium Club Moss Spores

A Teflon "wand" (anything made of Teflon)

A Laser Pointer (use a lens to expand the beam to a diameter of about 1 cm)

A Variac (or other brand) variable transformer.

### Suggested Ion Trap Assembly



The above schematic shows a typical configuration for a ring-type ion trap. The transformer provides a 60-Hz high voltage to the ring above the chassis. Earth ground is the other side of the circuit. Two load resistors are attached to the transformer output (for safety redundancy) – both are 10 M $\Omega$ , 10 W resistors.

Note that this circuit provides triply redundant electrical safety: 1) The current to the ring is limited by a 10 M $\Omega$ , 10W load resistor, limiting the current to less than 1 mA; 2) A second load resistor also limits the current at the ground side of the transformer; and 3) The chassis is grounded.

The goal of this safety is to limit the current that could be accidentally sent to a user or

onlooker. Touching the ring electrode could result in an electrical shock, but it would not be dangerous as long as the current-limiting resistors are in place.

We strongly recommend that you:

- 1) Bolt the transformer securely to the \*metal\* chassis.
- 2) Be sure all electrical connections inside the chassis are secure and properly insulated. This should be done by a qualified person with experience building high-voltage electrical hardware.
- 3) Bolt the chassis shut, so nothing can touch the high voltage in front of the current-limiting resistors.
- 4) Be sure the third prong of the outlet used is properly grounded.

Note again that the ring trap electrode will be at a high voltage. Touching it during operation could deliver an electrical shock. However, the electrical shock will not be dangerous as long as the delivered current is low. (Be sure you understand high-voltage safety before constructing any ion traps!)

We recommend driving the trap using a Variac, since then you can vary the high voltage to see how that affects the trap. If you plug the above circuit into the wall directly (which is fine), then you always have the full trapping voltage.

### Shielding Air Currents

The ion trapping forces are not large, so air currents can drive ions out of the trap rather easily. With a single person in a quiet room, it is possible to trap ions without air shielding, but the trapping will probably not be robust. Robust trapping requires shielding. A cardboard box of some kind is usually adequate, with small holes or slots to let the laser in and to introduce ions.

In a crowded lecture hall, it may be necessary to provide better shielding – for example sending the laser in through a plastic window, viewing the trap through another window, and using a closeable shutter to load ions. You will likely have to determine your own shielding needs with some trial-and-error.

Stray DC electric fields may be a problem if you use common plastics near the ring electrode. Nonconducting materials can accumulate substantial surface charges that distort the trap. Therefore, using a plastic box for an air shield may adversely affect your ion trap performance. Surface coatings (such as oils) can reduce surface charging effects. We have found that cardboard does not charge up too badly, so it makes an effective air shield.

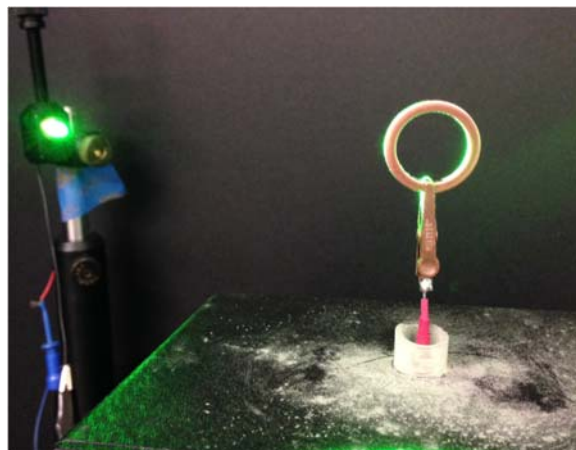
### **Our Set-Up**

These photographs show an ion trapping set-up we have used at Newtonian Labs.

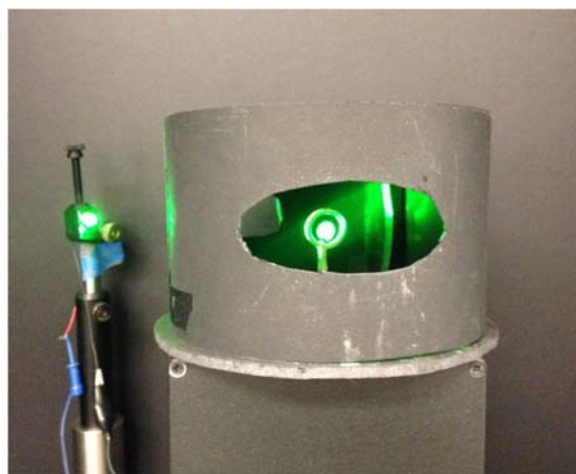


The above photo shows our overall trapping set up. Note that the transformer and its electrical connections are securely sealed inside the

chassis, which is properly grounded, for safety. The photo also shows the green laser (on a post) and a camera (for photographing trapped ions). Mounting the components on an optical breadboard is overkill, but it is handy for taking pictures. The cardboard back-board reduces air currents.



This photo shows a closer view of the top of the chassis. The high-voltage wire is shielded from the chassis with heat-shrink tubing and a piece of tygon tubing. The alligator clip is handy for connecting different types of rings. The dust at the top of the chassis is the residue from loading particles into the trap.



In operation, the ring electrode is covered with a crude cardboard air shield, which includes a top cover. The laser enters through a plastic window on the side, while the front hole is open. In this photo, several hundred ions are trapped in a ball within the ring electrode.

### **Charging the Particles and Loading the Trap**

We recommend using Lycopodium Club Moss spores, also known as *Dragon's Breath* (you can find out why online). These are essentially pollen particles, and they work great for trapping. They are quite round, with a typical diameter of 25 microns, plus or minus about ten percent. The particles are also cheap and readily available online if you need more. A normally sensitive person may sneeze now and then from breathing the dust, but otherwise the particles are harmless.

To trap particles, they need to be charged. We use a Teflon "wand" to charge and deliver particles to the trap. Simply rub the tip of the wand with a piece of cloth, pick up some particles (they are attracted to the charged tip), and drop them into the trap.

Teflon is a highly electronegative material, so it becomes negatively charged when rubbed with cloth. The dielectric particles readily stick to the wand tip when it is charged, and they usually come off with a negative charge. For optimal loading, you should tap the wand to sprinkle some particles down on the trap, rather than plunging the wand right into the ring. Teflon is an insulator, so it is okay to hold one end of the wand while touching the ring with the wand tip, but the electric fields around the tip of the wand will interfere with trapping.



With some care, it is possible to trap a lot of particles.

### **Advanced Trapping**

There are many possible trapping configurations; the setup shown above is just to get you started. See *NewtonianLabs.com* for more ideas.

### **More Information**

If you have any questions or are having difficulties, send an e-mail at [info@newtonianlabs.com](mailto:info@newtonianlabs.com). If your traps are working well, send us a picture. Good luck, and happy trapping!