Newtonian Labs

- Electrodynamic Ion Traps -

Why our High-Voltage Ion Traps are Safe

The *Electrodynamic Ion Traps* experiment uses high voltage to trap charged particles – up to 6 kV AC (at 60 Hz) and up to 1.5 kV at DC. With such high voltages, you may naturally be concerned about safety, especially when students are involved. We at *Newtonian Labs* are extremely safety conscious, and we have built the EIT experiment with safety in mind. What follows is a description of our high-voltage design strategy, and how this makes the instrument safe.

Let us begin with an old adage in the electrical business – *it's the volts that jolts, but it's the mils that kills*. In other words, what matters is not so much the voltage alone, but rather the continuous current it can deliver to your body.

Looking at that current, there are different thresholds for safety. A current of 1 mA 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 in current, 10 mA will give you a respectable shock, and 100 mA could be lethal. Of course it depends on how the current goes through your body (through the heart, for example, is especially bad), and it even depends on the AC frequency (e.g., 60 Hz current is worse than DC).

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 possibly deadly shock.

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 the EIT experiment, starting with the HV-DC side (see the <u>*Instrument Description*</u> document, available online at *NewtonianLabs.com*).

We use a DC-DC converter module to supply the HV-DC, up to 1.5 kV, and this has an internal current limit of 0.8 mA. In addition, the output terminals are both connected to 2 MOhm current-limiting resistors. Thus the steady-state current cannot get above the detection threshold of 1 mA.

In addition, the capacitance of the DC electrodes are tiny, of order 10 pF or less, so the shock energies ($CV^2/2$, with V at most 1500 volts) will be limited to some tens of *micro*-joules. Rubbing your shoes on the carpet will deliver a much bigger jolt than that. If you want to try a test yourself, touch one of the DC electrodes directly with a grounded wire. You will not see sparks fly; even in a dark room you cannot see any sparks this way.

The situation is similar with the HV-AC transformer. Both output terminals are connected to hefty 10 MOhm current-limiting resistors, so again the maximum available current is below 1 mA. The relevant capacitances are very low, as with the DC case, so again the stored energies are negligible. If you touch one of the AC electrodes (we have), you will experience a mildly unpleasant tingle, but not a shock.

It is conceivable that a wire inside the EIT chassis could break, so we designed fail-safes for this possibility. One is that the chassis is grounded, so a broken wire will most likely short to the ground, and not to a person. Another is that the current limits remain in operation even if any single wire breaks. For real damage to occur, several wires would have to fail together, creating some highly improbably short to a person and not to the chassis. Finally, we took measures to attach those current-limiting resistors especially strongly attached, just in case.

You experience high voltages quite often without knowing it. Rubbing your shoes on the carpet can easily generate 10 kV or more. It can give you an unpleasant static shock, but the energy is not sufficient to hurt you.

If you visit Wal-Mart, you can find bug zappers that look like tennis rackets. These cost a few dollars and can deliver a respectable jolt. (There are quite a few YouTube videos showing people sticking their fingers into the mesh electrodes on camera, just for the show.) Here the shock energy was designed to be enough to kill a bug, but not enough to harm a person.

The EIT experiment, on the other hand, cannot even hurt a bug. Very tiny currents are needed to drive the ion traps, so the instrument can only deliver very tiny currents.

It is possible to circumvent one of our fail-safes if the EIT chassis is not properly grounded, and this can happen if your 110 VAC outlet is improperly wired (with no ground connected to the third prong of the outlet). We therefore included an outlet tester in the EIT chassis, and we ask that you plug the instrument only into properly wired outlets. Note that a missing chassis ground would not itself be a serious problem (the current-limiting resistors are still there). It just makes sense to have a properly grounded chassis, just in case.