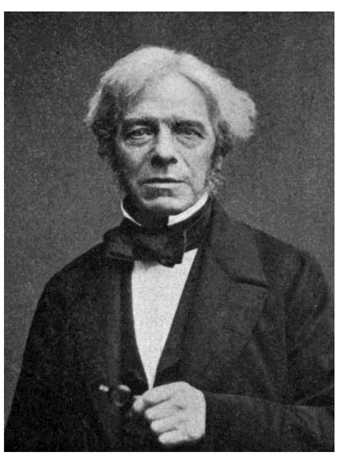
The Faraday Cage: What Is It? How Does It Work?

Introduction

It is a well-known secret (there's an oxymoron for you!) among electrochemists that a Faraday cage is used to reduce noise. While this "secret" is fairly widely known in electrochemistry circles, you would be hard-pressed to find good information regarding the use and function of Faraday cages in electrochemistry textbooks. In fact, a cursory inspection of the many books on our bookshelves here at Gamry produced one result in *Electrochemistry for Chemists*: "[Voltammetry at microelectrodes] usually requires that measurements be done in a Faraday cage (a shield against electronic noise)."[1]

So kudos to Sawyer, Sobkowaik, and Roberts for the only mention we could find on a quick search. They also got the usage correct: noise-reduction, particularly important in low-current experiments (such as microelectrode voltammetry). Of course, there is no mention of set-up, grounding, or other experimental techniques that benefit from the use of such a nifty device, like EIS or corrosion measurements on highly resistant materials. Or really, even what a Faraday cage actually is.

So Who Was this Faraday Guy?



The great experimentalist Michael Faraday is certainly best known for his work with magnetism and electricity. He was a popularizer of science, the Carl Sagan or Neil deGrasse Tyson of his day, authoring the popular *A Course of Six Lectures on the Chemical History of a Candle*. Far more interesting, though, may be that he once rejected knighthood, twice turned down the presidency of the Royal Society, and also declined to be buried in Westminster Abbey.

Faraday was not terribly good at math. His grasp of the myriad phenomenon he studied was more intuitive in nature. He was a tinkerer. Among the many things we can at least in some part thank him for today are electrical power (as generated by electromagnetic induction), benzene (a very useful little carcinogen) and, naturally, the Faraday cage.

What is a Faraday Cage?

In Faraday's studies and experiments regarding charge, magnetism, and their interaction, he found that charge on a conductor only resided on the outer surface. Further, he discovered that nothing inside that conductor was affected by any change in electrical charge on the outside. Later, field theory was based on Faraday's work, and he did believe, contrary to the accepted view at the time, that an electric field extended into space beyond a charge. Having somewhat better understanding of things now, we know that the electrostatic repulsion of like charges causes a redistribution of charge to the outside of a conductor resulting in a net electrostatic field within the conductor of zero. "Within the conductor" means any space enclosed by a *continuously* conducting layer.

This phenomenon produces a pretty neat result: any and all noise with an electronic component that exists outside the cage is completely cancelled within that space. This is the same mechanism we electrochemists use to justify disregarding electrostatic fields in highly conductive electrolyte solutions. This is also a two-way street: any noise created inside the cage is prevented from escaping to the outside world. This is what keeps us safe near a microwave oven.

There are three little things to keep in mind. First is that breaks in the cage cause gaps that allow for penetration by outside electromagnetic (EM) fields. For a mesh, or a hole drilled into a solid box, the penetration of EM radiation is limited to oscillations that have wavelengths shorter than twice the diameter of the opening. So a 1

[1] D.T. Sawyer, A. Sobkowiak, and J.L. Roberts, *Electrochemistry for Chemists*, 2nd Ed., John Wiley & Sons, 1995, p. 79.

cm opening allows 2 cm and shorter wavelengths, which correspond to 150+ GHz noise.

A second, and more relevant concern, is a long, or even complete break in continuity of the conductive material. Access to a Faraday Cage via lid or door creates the real possibility for such a break in continuity. If one side is discontinuous, even if it is conducting, then charge may not redistribute properly, the cancelling effect will not exist, and a non-zero field will exist within the cage. Use of a wire to connect discontinuous edges can help with low-frequency work, but is often insufficient for experiments that have higher operating frequencies and speeds.

A final concern is the conductivity of the cage. This is seldom much of an issue, but as the size of the cage increases it can become a larger concern. The more resistive the conducting layer is, the slower charge redistributes, resulting in a non-cancelling field.

When to Use a Faraday Cage

Use a Faraday cage whenever possible, for it always reduces noise, particularly power-line (mains) noise which is ubiquitous—every laboratory in every building in every country with an AC power-grid. Some experiments see a larger effect than others, however. Those are experiments that deal with low currents or high frequencies, and experiments where very precise (and accurate) measurements are required.

Just about anyone doing physical electrochemistry (CV, pulse voltammetry, chronoamp, etc.) falls into the latter category—and when tiny electrodes are involved, then both. Corrosion may not often require as much precision and accuracy, but corrosion-resistant alloys easily can lead to measured currents in (and below) the nA range, where a Faraday cage is definitely needed. EIS involves higher frequencies, and so any reduction in noise is welcome. The safe answer is to use a Faraday cage whenever it is physically possible to do so. If your cell current does not exceed 1 μA, use a Faraday cage.

In Figure 1, cyclic voltammograms taken on a resistor-capacitor dummy cell are shown in and out of a Faraday cage. They show that it is possible to move into a shielded environment in such a way as to still have noise. This means that we have to discuss how to set up and use a Faraday cage properly.

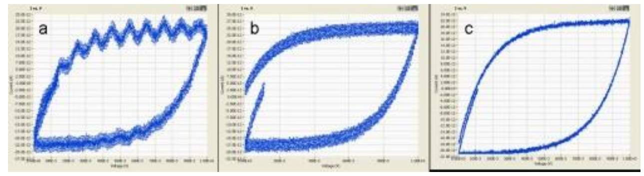


Figure 1. Three CVs collected on the same RC dummy cell with the same parameters (0–1 V at 0.5 V/s with 1 kHz acquisition frequency) using a Gamry Series G 750 potentiostat and VFP600 Virtual Front Panel software. (a) collected outside a Faraday cage; (b) inside a Faraday cage that was not grounded to the potentiostat; (c) in a Faraday cage that was grounded to the potentiostat (current values are ~ 25 pA).

About Grounding

All electrochemical measurements are referenced to some ground potential in the potentiostat. Because of that, effective use of a Faraday cage for electrochemical experimentation must include proper grounding. While the grounding issue can become very complicated, the basic reasoning is fairly simple. The whole of the Faraday cage (including the interior) is at a constant potential, and—if not connected—this potential can be quite different from the potentiostat's ground reference. That is: there can exist large AC voltages between the interior of the cage and the ground reference.

This voltage-difference capacitively couples into the electrodes, making the supposedly shielded noise part of the measurement. For this reason, always connect a Faraday cage to the instrument ground. The large majority should also have their potentiostat earth-grounded. With some potentiostats this is by default, but for potentiostats designed to operate with floating ground, like all Gamry models, this is done separately.

Earth-grounding is not always a good idea, however. If you are doing an experiment with a grounded electrode, a Faraday cage may help, but not if it is tied to the same earth-ground. If you want to use a grounded electrode in a Faraday cage, you ought to make sure that the Faraday cage and potentiostat ground reference—while still connected for the reasons mentioned before—are *not* earth-grounded in this case your potentiostat must be capable of floating-ground operation.

What Faraday Cage to Use?

Why, any of them! We would certainly be very happy if you chose to use Gamry's VistaShield Faraday cage, which offers lots of versatility and sits handsomely on your laboratory benchtop.

Figure 2. Gamry's VistaShield Faraday cage.

The truth, though, is that there is little difference in the noise-cancelling behavior between well-constructed Faraday cages. There may be a good deal of difference in how well or easily you can connect your particular experiments. You may need a large box to accommodate your experimental apparatus, or entry ports to bring in gases or water, or a material like stainless steel to deal with corrosive vapors and solutions. You may want to see what is going on, or have as much light blocked out as possible. In the end, a cardboard box wrapped in aluminum foil will give the same noise-reduction as a solid 24-karat-gold box, provided that the continuity throughout each is the same. Of course, cardboard is probably not the sturdiest material to use, and solid gold would be downright silly, but you get the point.

Wood-frame and copper or aluminum mesh are common for the home-built Faraday cage. Solid metal boxes are good choices, but if you are not buying one that is specifically designed for good electronic shielding, pay close attention to door edges and ensure that there is good electrical contact between the sides.

Summary

Use a Faraday cage whenever your experiment permits, particularly when measuring currents below ~1 µA or impedances above ~10^5 Ω. Ensure that it is grounded properly: for Gamry users that means connect the floating-ground lead to the Faraday cage, and then either earth-ground the potentiostat via the ground lug if using a Reference series, or connecting the short earth-ground lead to the floating ground lead for a Series G.

When building or buying a Faraday cage, make sure that it will accommodate the experiments you run and that you have the space for it. Don't forget about cable-strain relief (ring-stand bar or tie-offs inside the cage) and access for gas and water as well as the cell cable(s). If you think you may want to use a magnetic stirrer, avoid Faraday cages made with magnetic materials. We think it is nice to be able to check connections and see what's happening inside without breaking the shielding, so we've got a big glass window with a conducting coating on our VistaShield Faraday Cage.

Happy experimenting!

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