Conceptual Photoelectric Effect.

My "ascension" from the high school classroom to the university demonstration lab 25 years ago opened my eyes to many demonstrations that made me wish I still had a class to show them to. At the top of that list was a wonderfully elemental demonstration of the photoelectric effect by discharging an electroscope with a UV light shining on a zinc electroscope electrode.

It touched all the important demo "bases": Simple, visible hardware, real-time cause & effect behavior, and dramatic counter example reversal. BUT…the hardware involved was a big antique electroscope and a machined disc of unalloyed zinc—things I could not find in my high school storeroom or budget.

The special zinc electrode compensates for the low energy UVA (~400nm) photons emitted by party-store blacklights. Zinc has one of the lowest electron work functions of stable, affordable metals. And, of course, Penn has a gorgeous old brass gold-leaf electroscope in a lantern slide projector with appropriate hard rubber (-) and glass (+) static rods. So this demo also required the legacy and budget of an Ivy League University…until very recently. After a generation of development, LED technology has marched all the way through ROY G. BIV's name and landed not only at UV, but UV-C! That's the nasty short wavelength that sneaks past bad ozone layers and wreaks havoc on skin cells, or any cells for that matter; like bacteria, virus, or any other uninvited microbes seeking pandemic fame. It works well at industrial power levels, but when reduced to insurable consumer strength, the margin of safety frequently extends to about half of the critters that should have been sterilized. But the photons are still UV-C (275 nm), there just aren't enough of them for all the germs. With COVID demand combined with low-cost LEDs, the market flooded fast, and discounted water and phone sterilizers are all over the internet. Most take care to make direct skin and eye exposure difficult, because 275 nm photons can knock electrons off most atoms, not just zinc! So, one of these UV-C sources will discharge most negatively charged electroscopes; and as a powerful counter-example, NOT discharge a positively charged electroscope.

There are many ways to produce negative and positive charge, but a great way to illustrate the triboelectric series of increasing affinity for electrons (ref. Wikipedia) is to use a piece of PVC pipe, a microfiber cloth, and a tube or rod of Plexiglass (acrylic). Electron affinity is highest in PVC, followed by microfiber, followed by Plexiglass. So the same microfiber cloth gives up electrons to PVC (making it negative), but takes electrons from Plexiglass (making it positive).

Post Presentation Note

The clever(?) dual use of the microfiber worked fine on the comfortable low-humidity days in the week before the meeting. I put the microfiber cloth in a Zip-Lock bag to keep in clean in transit. Meeting day dawned damp and muggy, and the room we used had open windows rather than air conditioning. I set up the demo, took the cloth out of the bag and tested it. It worked, but not as well as earlier in the week. The second try failed to produce any negative charge on the PVC. The acrylic rod still turned positive, but no audible crackles. The demo was bailed out by using the positive rod and induction to put a negative charge on the electroscope. But in the future a woolen or polyester fleece cloth will be included as a back-up.

A second visible and qualitative photoelectric demo can be done with a small neon indicator lamp (NE-2, F6, or similar). These bulbs need to be used in series with a resistor in the 20kΩ to 30kΩ range to limit current when used with 110 volts. They typically turn on between

80 and 100 volts. If connected to a variable transformer, that turn-on point can be found on the knob (or with an A.C. voltmeter across the bulb leads). If the voltage is set just below the turn-on value, the bulb can be kicked into glowing with a violet (~400nm) laser. With a little fiddling you can find a setting that works well with violet, just barely starts with green and does nothing with red. After a basic explanation of the source of the neon glow as electrons that gained enough energy to briefly jump to a higher level and then drop back down while releasing the energy as light, the use of light to deliver that last energy step makes sense. The point is emphasized by the emission of a color that was not provided. The Planck-Einstein formula ($E = hf$) is illustrated by the observation that lower frequency red light does not work as well as higher frequency violet. (For those of you who follow that logic to using your newly purchased UV-C sterilizer on the neon bulb, you will be disappointed. Short wavelength UV is blocked by the glass bulb—which is why I referred to the 400nm laser as "violet").

This demonstration does not lend itself well to a quantitative check of Planck's equation because A.C. voltage does not present the bulb with a constant single voltage. A regulated D.C. voltage source that runs from 0 to at least 100 volts would be needed (although a string of 9V batteries would be more affordable). That work has been impressively documented in the AJP article by Gonzalez-Laprea et al. referenced below.

Sources

Electroscope: Arbor Scientific
https://www.arborsci.com/collections/electrostatics/products/demonstration-electroscope

UV Disinfecting Light: Amazon
https://www.amazon.com/Light-Disinfecting-Wireless-Charging-Included/dp/B08L9TFR97

Neon bulb photoelectric behavior:

Photoelectric Effect Measurements on a Conventional Neon Bulb, Jesus Gonsalez-Laprea *and* L. J. Borrero-González
American Journal of Physics **89**, 969 (2021); https://doi.org/10.1119/10.0005016

F6 neon bulbs: (one of many sources, NE-2 bulbs also work well):
https://www.ebay.com/itm/374596838556

Bill Berner.
berner120@gmail.com


globe
UV·C LIGHT
Disinfecting Wireless Charging Hub
kills up to
99.9%
of germs, bacteria and other harmful pathogens.
Wireless Charging
5+ minutes
Disinfection Time
Up to 2 inches (5 cm)
Disinfection Distance
254 nm
Quartz Wave Technology
15 minutes
Auto Off
Power:
Micro USB cable (included)
1. Test results provided by independent certified laboratory. When used as directed against Staph, E. Coli, salmonella and influenza. To help effectiveness, surfaces should be relatively clean and free of grime, dust, and other materials that will prevent the germs from being directly exposed to UV-C Light.
2. Please review the instruction manual carefully before use, to ensure proper and effective use.