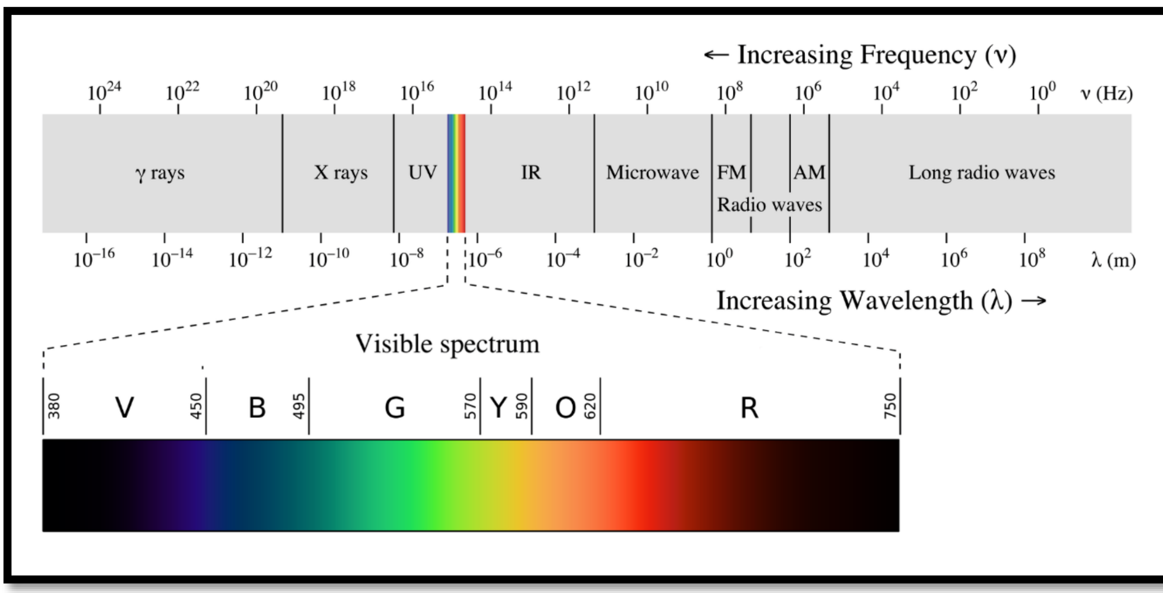
Insight into the spectral output of UV sources manufactured from the 1800s - early 1900s.
Jeff Behary, Turn Of The Century Electrotherapy Museum



In terms of human sight, colors appear to our eyes from a narrow band of the electromagnetic spectrum from about 380 to 740 nanometers (Violet, “Indigo”, Blue, Green, Yellow, Orange, and Red, a list first compiled by Sir Isaac Newton in the 17th century – though the term “Indigo” has since been dropped from most references.)

In colloquial terms, we also speak of “invisible” light or “rays”: “Chemical” or “Actinic” Rays (ultraviolet radiation) beyond the violet end of the spectrum and “Heat Rays” (infrared radiation) beyond the red end of the spectrum. This brief summary of investigations focuses on ultraviolet radiation produced by the earliest methods of generating them artificially in the laboratory.

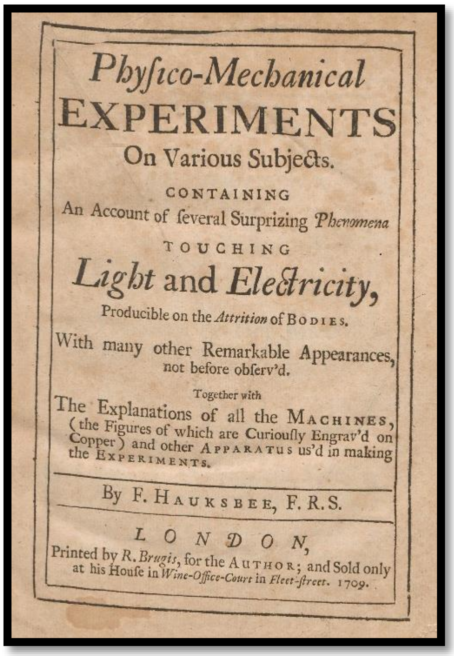
The ultraviolet portion of the electromagnetic spectrum falls from 10 to 400 nanometers. By wavelength, these rays are further divided into unique categories similarly to colors; and while we cannot see them we can certainly see the effects they have on various materials, both organic and inorganic:

Name	Abbreviation	Wavelength range
Red		620nm – 750nm
Orange		590nm – 620nm
Yellow		570nm – 590nm
Green		495nm – 570nm
Blue		450nm – 495nm
Violet		380nm – 450nm
Ultraviolet A	UVA	315nm – 400nm
Ultraviolet B	UVB	280nm – 315nm
Ultraviolet C	UVC	100nm – 280nm
Near Ultraviolet	NUV	300nm – 400nm
Middle Ultraviolet	MUV	200nm – 300nm
Far Ultraviolet	FUV	122nm – 200nm
Hydrogen Lyman-alpha	H-Lyman-α	121nm – 122nm
Vacuum Ultraviolet	VUV	10nm – 200nm
Extreme Ultraviolet	EUV	10nm – 121nm

UVA or long-wave ultraviolet radiation is known mainly for its Black light effects; it is not absorbed by the ozone layer in the atmosphere. UVB or medium-wave ultraviolet radiation is only partially absorbed by the ozone layer and produces erythema of the skin (tanning, burning). UVC or short-wave (germicidal) ultraviolet radiation are completely absorbed by the ozone layer but when produced in the lab cause erythema effects on the skin and can rapidly cause photo-keratitis of the corneas (flash-burn, welder's burn) though most often with a delayed reaction of several hours after the exposure. Several of the lamps outlined in this article can produce photokeratitis from just seconds of exposure.

Unless the eyes and head are fully covered, normal safety glasses are not good enough protection to the wavelengths present in these sources. Full face-shields, goggles, hoods, and protective clothing were worn to take all measurements in this investigation.

The earliest experiments of electricity under vacuum were done by Francis Hauksbee in England around 1705. He noticed the peculiar glow of mercury (seen previously by investigators when carrying barometers) by the friction of mercury against the inner glass walls of the tubes. Artificial light was produced that he referred to as "the mercurial phosphor". He went on to produce a series of novel machines for the production of light published in an epochal volume of work *Physico-Mechanical Experiments on various subjects containing an account of several surprising phenomena touching light and electricity producible on the attrition of bodies with many other remarkable appearances not before observ'd* (1709).


Physico-Mechanical
EXPERIMENTS
On Various Subjects.
CONTAINING
An Account of several Surprizing Phenomena
TOUCHING
Light and Electricity,
Producible on the Attrition of BODIES.
With many other Remarkable Appearances, not before observ'd.
Together with
The Explanations of all the MACHINES, (the Figures of which are Curiously Engrav'd on Copper) and other APPARATUS us'd in making the EXPERIMENTS.

By F. HAUKSBEE, F. R. S.

LONDON,
Printed by R. Brugis, for the AUTHOR; and Sold only at his House in Wine-Office-Court in Fleet-street. 1709.

The author has not attempted to measure the wavelengths of light produced by machines of Hauksbee's era because of their extremely fragile nature.

The first sources of UV investigated will be the result of the work of Sir Humphrey Davy. Davy was the first investigator to strike a voltaic arc between carbons, something that a century later became a practical light source and source of UV radiation for experimental purposes. Davy also experimented early on electrifying mercury under a vacuum, the hardest vacuums obtainable at that time period. He proved when mercury vapor was present, glow discharges could always be induced even in vacuums where no discharge could take place had the mercury not been present. The author had one of his tubes replicated for this investigation in Europe using a glass common to that time period… and while only the longer waves of ultraviolet could penetrate the glass it did prove he was generating ultraviolet radiation (even though it wasn't his intent).

Carbon Arcs were first adopted as methods of street-lighting around the world, the light was so bright it was limited to outdoor use and for use in overhead projectors (called "Magic Lanterns" in the time period). They produced a large amount of smoke, a great deal of heat, and required a large amount of electrical energy to operate – but prior to LEDs they were considered one of the more efficient light sources known. Plain carbons were modified with rare earth elements, metallic salts, and metal powders to produce rich diversified spectrums of both visible and ultraviolet radiation.

Niels Finsen began treating medical conditions with ultraviolet radiation, first using natural sunlight and later with carbon arcs. In 1903 he was awarded the Nobel Prize in Medicine and Physiology "in recognition of his contribution to the treatment of diseases, especially lupus vulgaris, with concentrated light radiation, whereby he has opened a new avenue for medical science." His work opened up a commercial market for UV lamps and medical research.

Carbon arcs were gradually replaced by solid metal electrodes, but there were difficulties in striking and maintaining the arcs, and the UV intensity greatly diminished as the electrodes became overheated. Bang invented a lamp with water-cooled electrodes that produced a steadier spectrum, though the device was cumbersome. Görl simplified the concept by using iron balls through which the condenser discharges from Leyden jars were passed using static electric generators or induction coils from the time period, but when significant powers were used they were also prone to overheating and arcing – at which point the ultraviolet intensities ceased, or portions of the spectrum diminished. This was corrected by Henry Piffard, Thomas Burton Kinraide, and other inventors by providing adequate heatsinks to the electrodes. The superficial cutaneous reactions from these later lamps provided an equal match to carbon arcs using a small fraction of the power needed.

Frederick Finch Strong, a physician from Tuft's university, took up ultraviolet investigation pre-1900 using special modifications of Geissler tubes with rock salt or quartz glass lens cemented to standard glass of the time period. He experimented with mercury vapors, acetylene gas, and iodine vapors early on as ultraviolet sources. The difficulty in making lamps pre-1900 were the cemented seals for the UV-transparent lenses. The lamps were short-lived because of the difficulty of keeping the seals vacuum- tight.

Peter Cooper Hewitt developed his famous mercury vapor lamp, however in operation the lamps were prone to cracking from the high temperatures present. Eventually quartz glass was experimented with because of its high softening point, though at this time there were not yet alloys of metal wire that could be fused in the glass and maintain a proper hermetic seal. Pools of mercury were used as electrodes to maintain vacuums, cast indium seals, complex graded seals (some containing more than 10 types of glass), and finally solid tungsten and molybdenum wires to maintain electrical connections outside of tubes while keeping the vacuum levels inside of the tubes intact. It was a process that took more than two decades to develop, and while ultraviolet experimentation was done during this period to kill bacteria, sterilize water, reduce volatile organic compounds, produce catalytic reactions, alter chemicals, treat skin conditions, and other kindred applications still used today it was greatly limited because of the cost, skill, and access to specialized materials of the time period.

With an increased interest in ultraviolet radiation from new products such as UV-LEDs and standard low pressure mercury vapor germicidal lamps, it is the author's intent to show the differences and similarities of UV sources from the last two centuries.

The reader may find of great interest how diverse the ultraviolet spectrums of the past were in comparison to most modern ultraviolet sources of single or limited spectrums. However, there is still much to be desired in the quest of knowledge in this subject matter. Many forms of very historic lamps have yet to surface, and it is very questionable how many still exist.

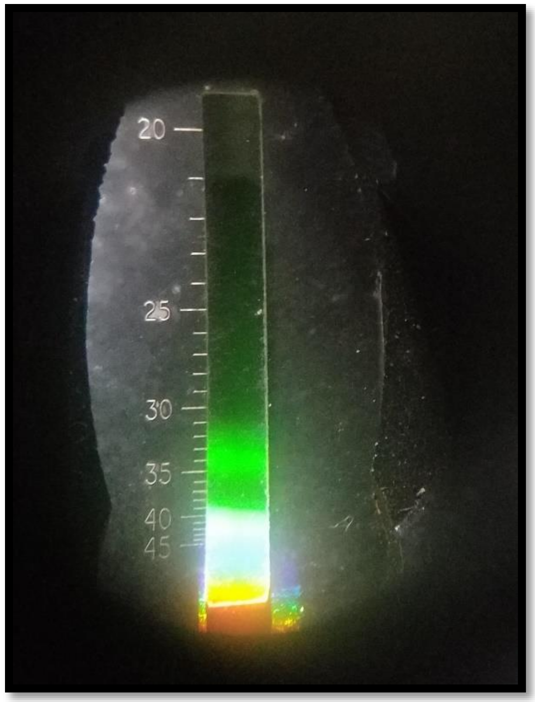
The lamps and apparatus used in this investigation are from the author's collection of antiques that span 500+ years from over 28 years as a medical and scientific historian. Some of these lamps are the only-known surviving examples.

Left: Peter Cooper Hewitt Lamp. (Early 1900s)
Right: Quartz Prism Spectroscope, R&J Beck Ltd. London (1920s)

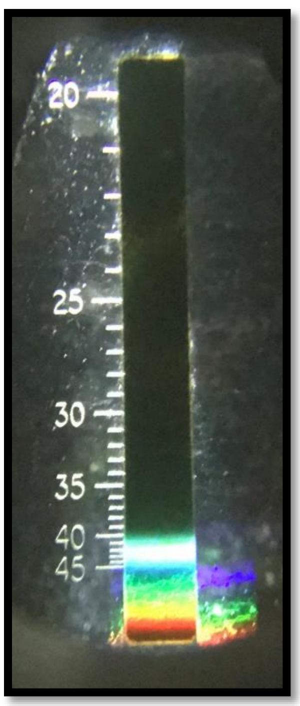
To measure UV spectra, quartz prism and lens spectroscopes are necessary. The author has several sizes of these ranging from hand-held to bench models over 6 feet long.

Adam Hilger of London made some of the finest historical instruments. For this article, measurements using a handheld R&J Beck Ltd. instrument were used as the results were purely for reasons of broad referencing. The numbers on the scale represent 100 Ångstroms, and can easily be converted to nanometers in modern terminology by just adding a trailing "0". The first spectrograph shows a modern UVC lamp operating at 254nm, though more exactly 253.7nm.

Left: Adam Hilger Spectroscope and Author's patent model Broadband Ultraviolet Sources. Right: Some of the earliest-known experimental ultraviolet lamps having a variety of unique seals and construction methods. Below: Various obscure seals in early lamps.

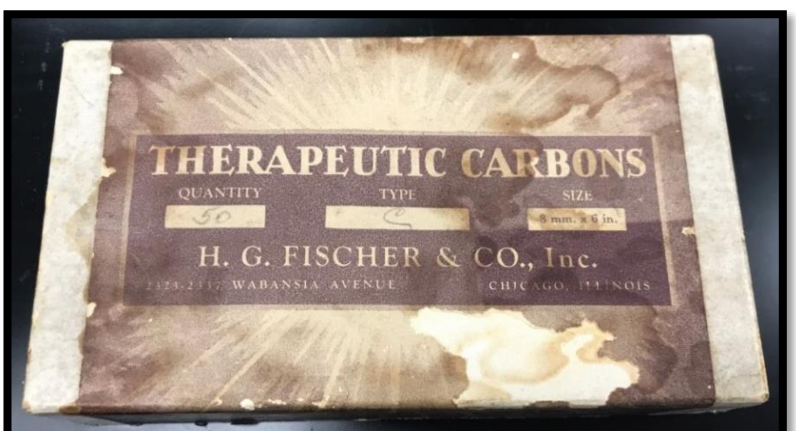


Left: Modern UVC lamp of United States origin (2020)
Right: The sun in South Florida on a typical afternoon (2020)

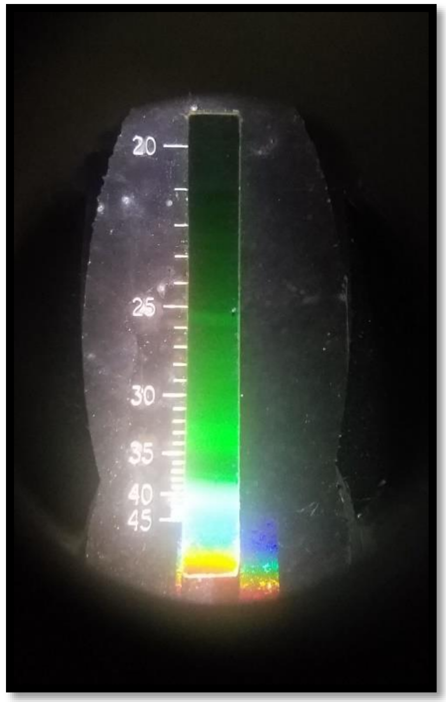


Left, Center, Right: Ultraviolet spectrums from recent off-the-shelf UV-LED products

Carbon Arc Lamps: Left: Charles Brush carbon arc lamp;
William Wallace Arc lamp (1878) (The first commercial carbon arc lamp.)
(Maryland Museum Of Electric Light/Chad Shapiro Collection).
Right: Two models sold for tanning purposes in the 1920s. (Author's Collection).

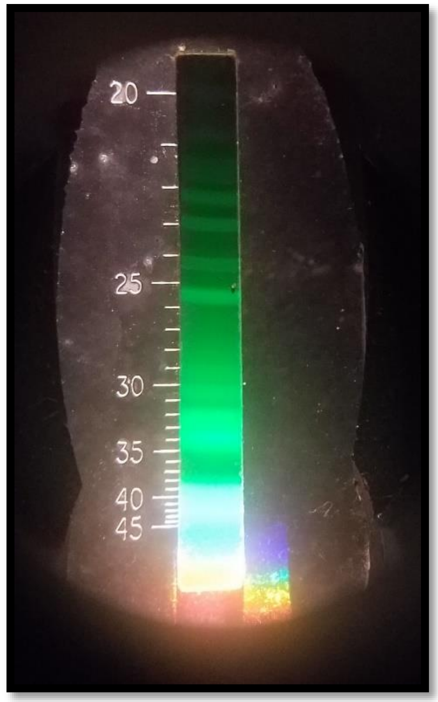


Arc carbons could be purchased in different diameters and with different metallic or Rare Earths additives to produce diverse spectra needed for specific purposes. (Lighting, germicidal, erythematic, infrared, and so forth.)



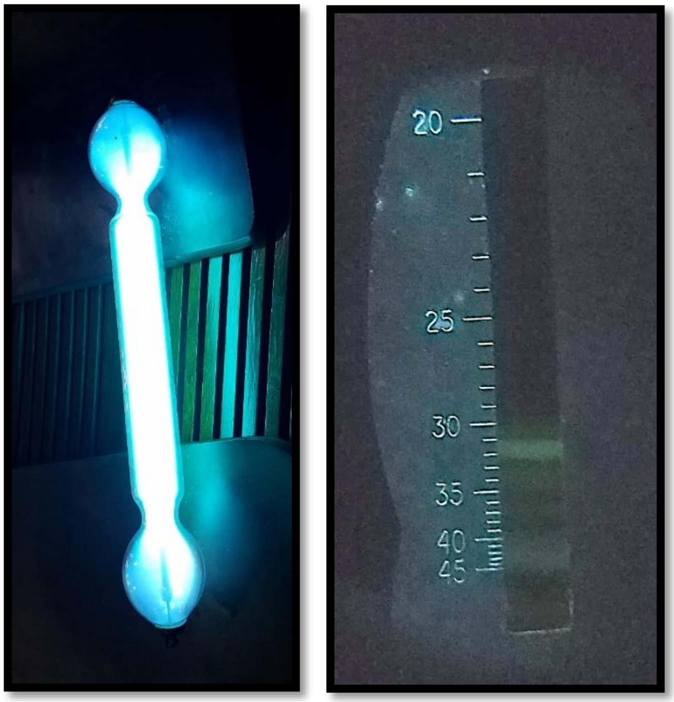
Left: Eveready Therapeutic Carbons
Right: Eveready Super Tan Carbons

Left: Actino Laboratories Prismatic Carbons
Right: Actino Laboratories Tungsten Loeb Duocore Carbons

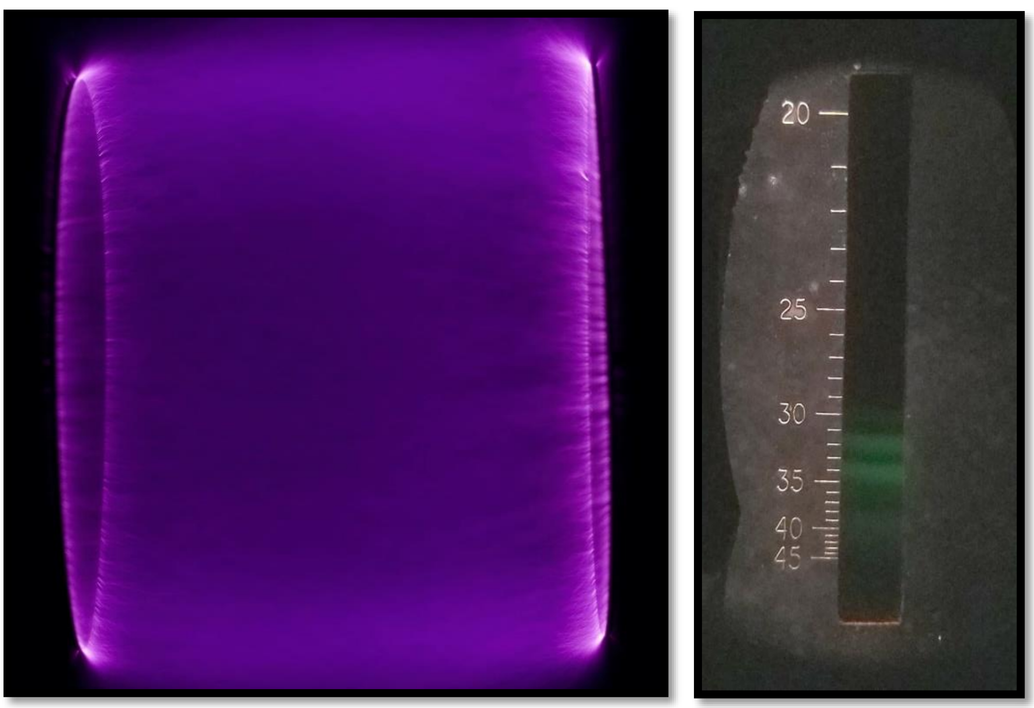


Left: Actino Laboratories Yellow Detoxicant Carbons
Right: Actino Laboratories Yellow Sunshine Carbons

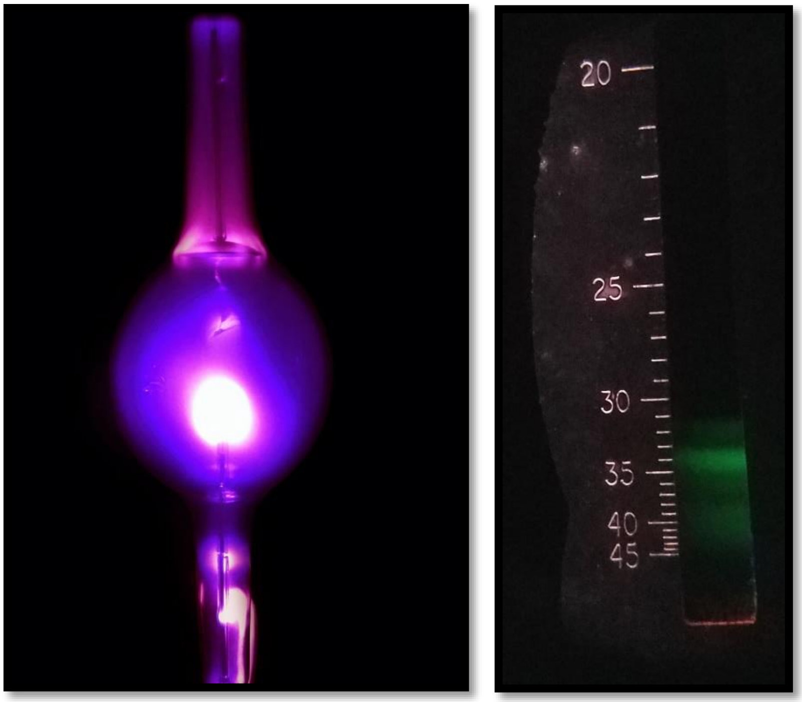
Left: Actino Laboratories: Blue Sun Carbons
Right: National Carbon Micro Projector Carbons



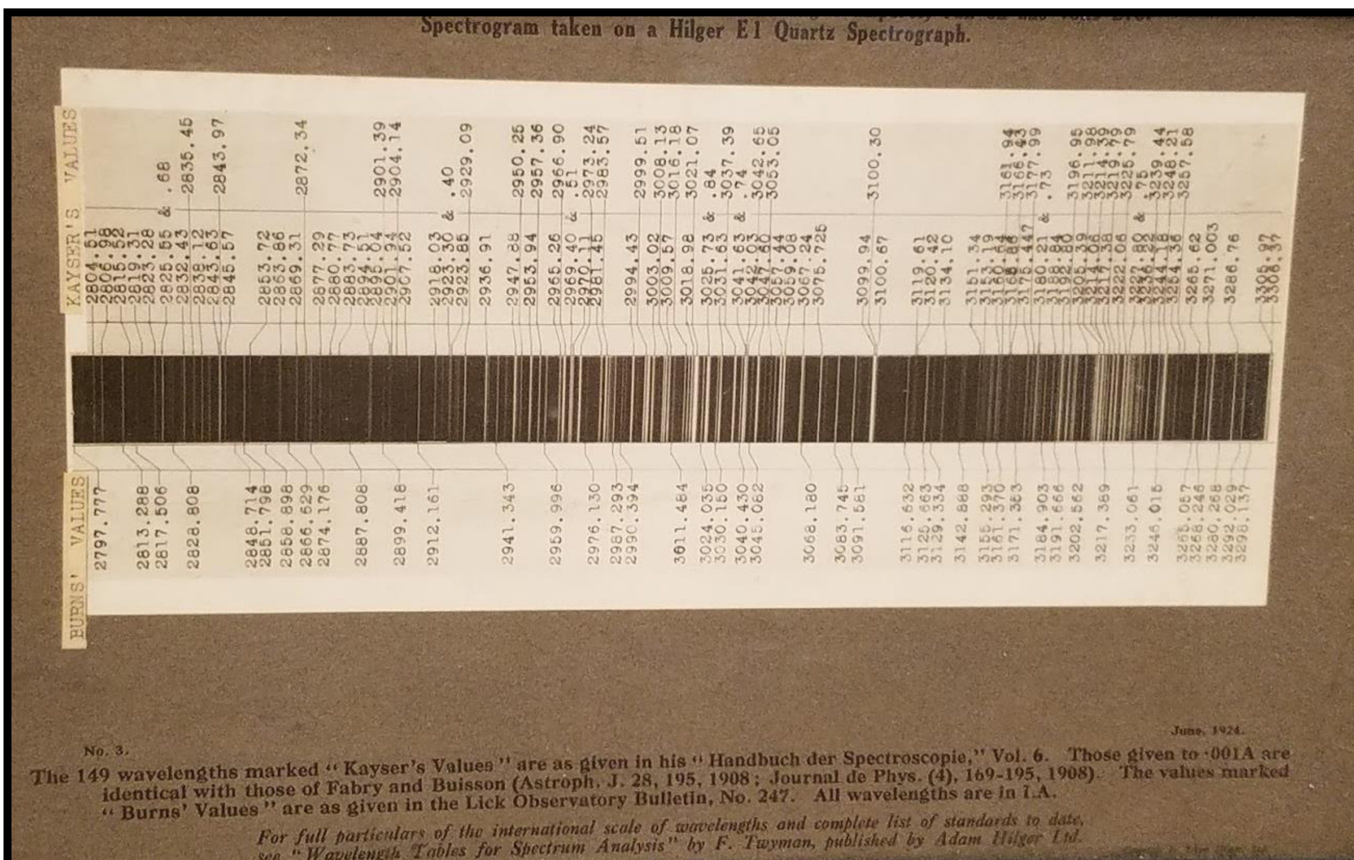
Sir Humphrey Davy Mercurial Vacuum Experiment (1821)



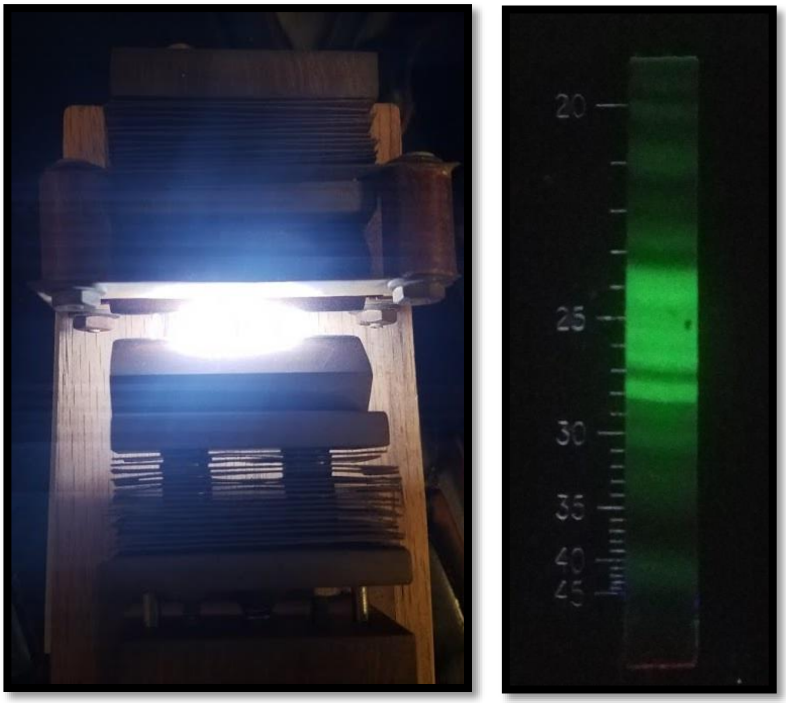
Corona Discharge from Tesla Apparatus (1892)
(Replica built by author.)



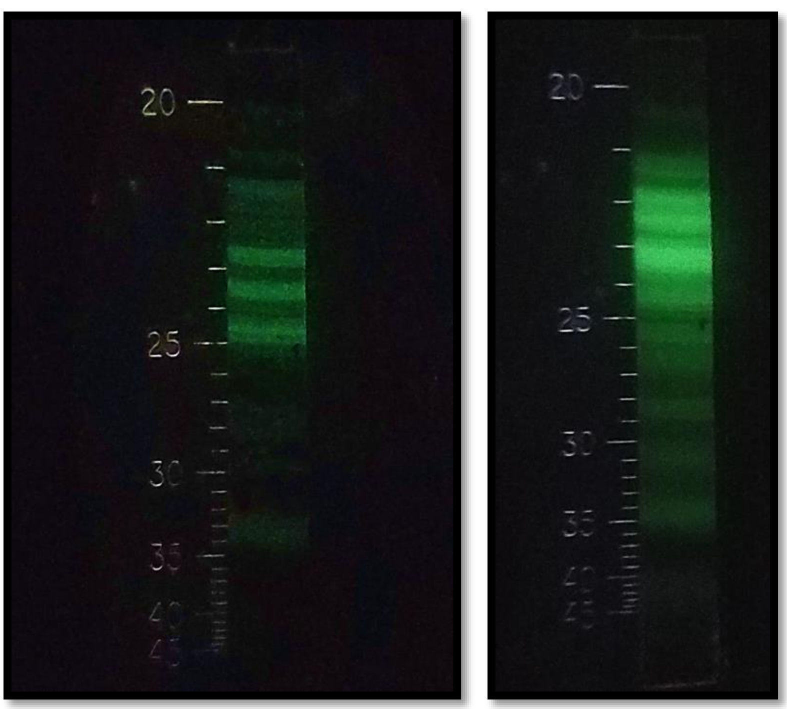
Swett & Lewis X-Ray Tube with low vacuum (1897)



Original Spectrogram for Iron Arc Spectrum (Early 1900s, Bang lamp)

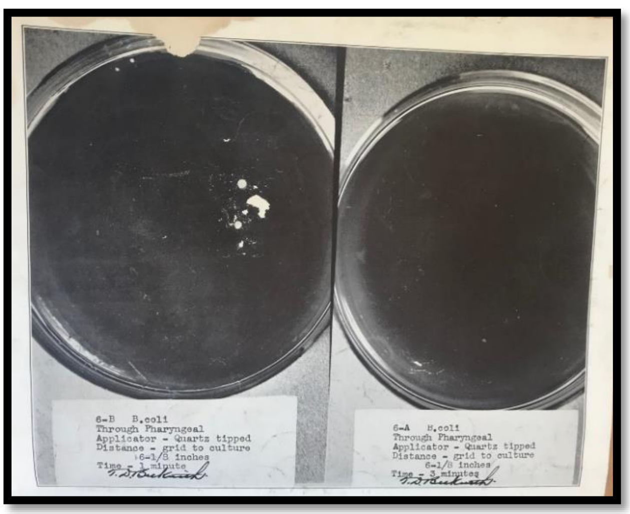


Iron Spark Condenser Discharge Lamp (Thomas Burton Kinraide, Patent 1904)
(Replica built by author.)

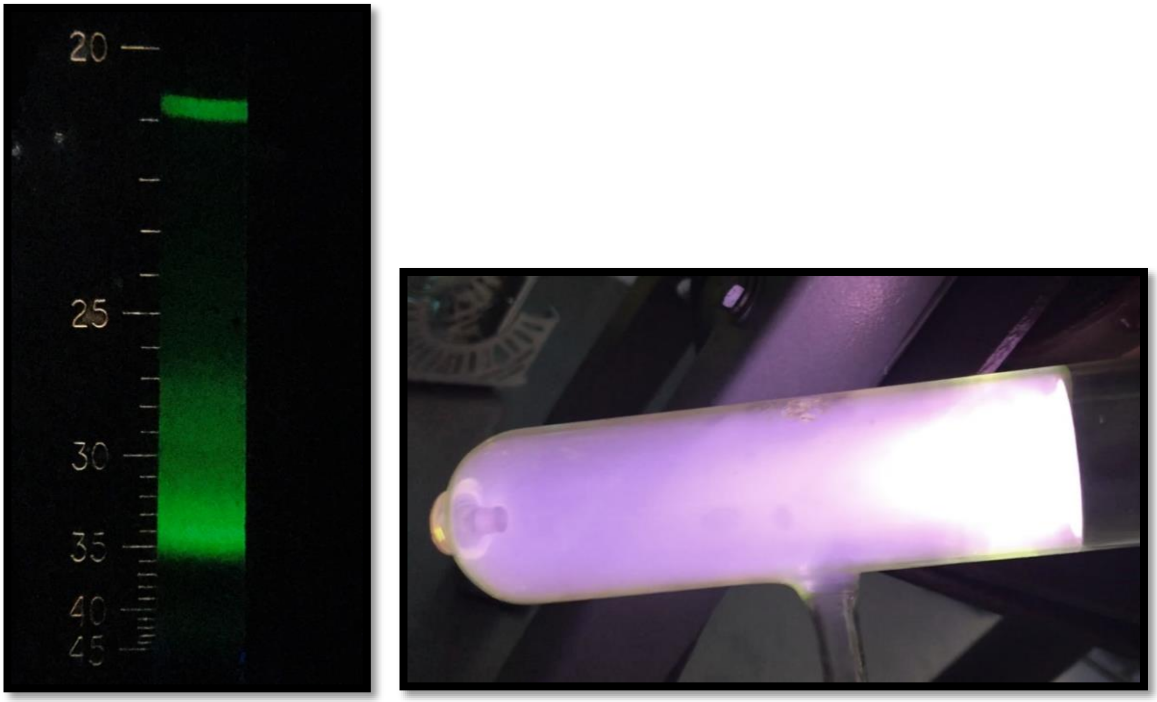


Left: Silver Condenser Discharge (James E. Seeley Patent, 1913)
Right: Nickel Condenser Discharge (Hector P. MacLagan Patent, 1927)

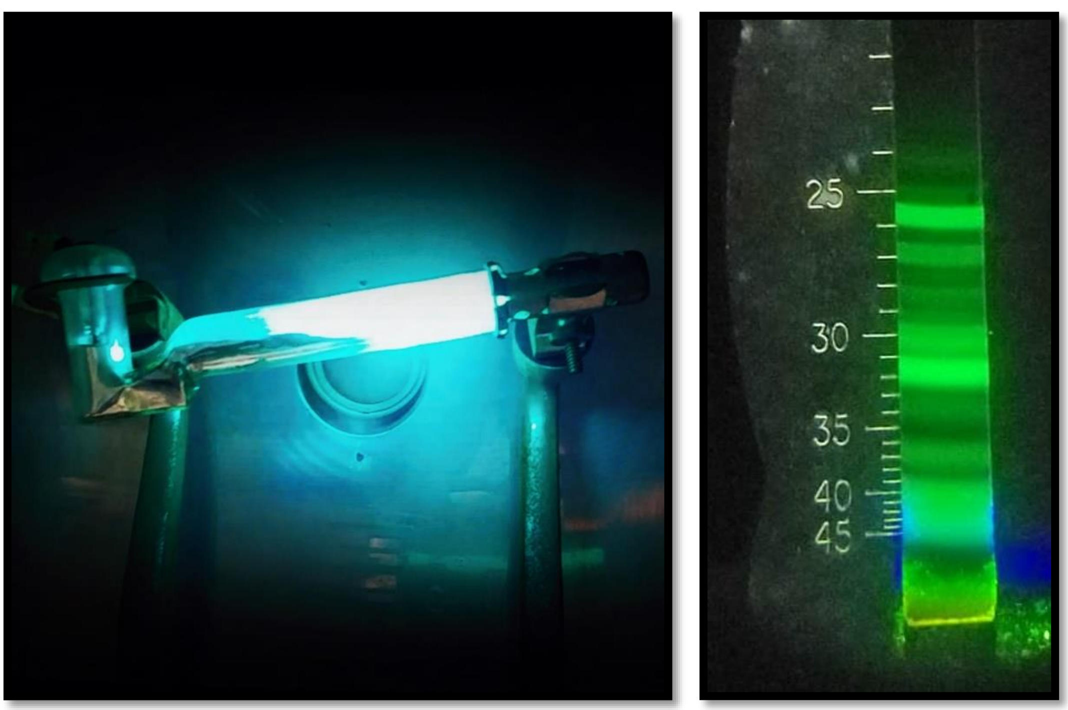
Dr. Frederick Finch Strong, Tuft's University. Early promoter of the uses of ultraviolet radiation.



Early records of killing bacteria in petri dishes with ultraviolet radiation.
(Frederick Finch Strong personal scrapbook, from the Author's collection)

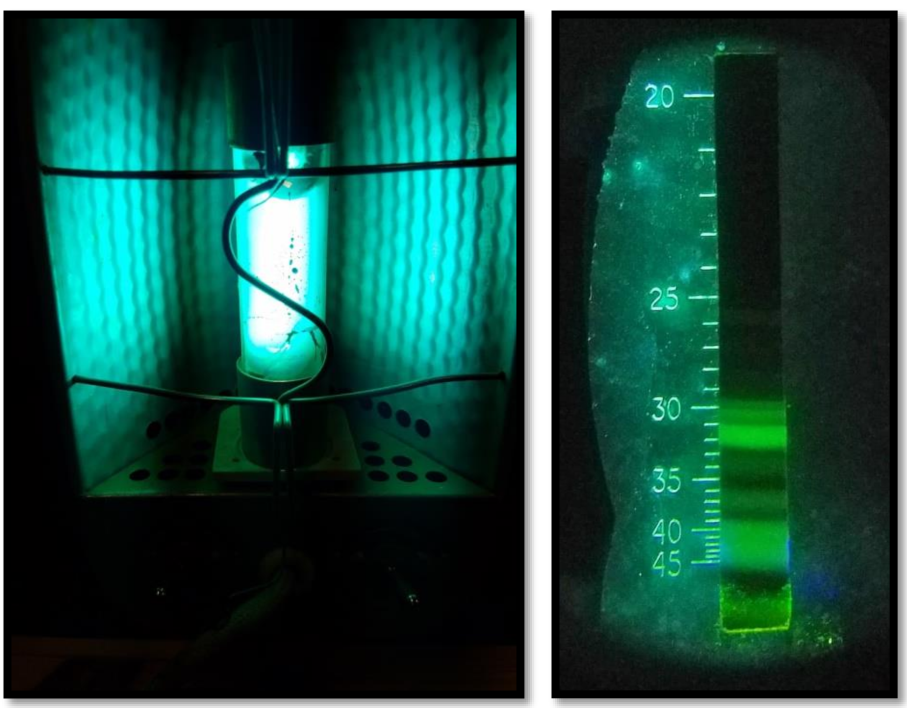


Frederick Finch Strong Ultraviolet Lamp with Iodine Vapor (1900)
(Replica built by author)



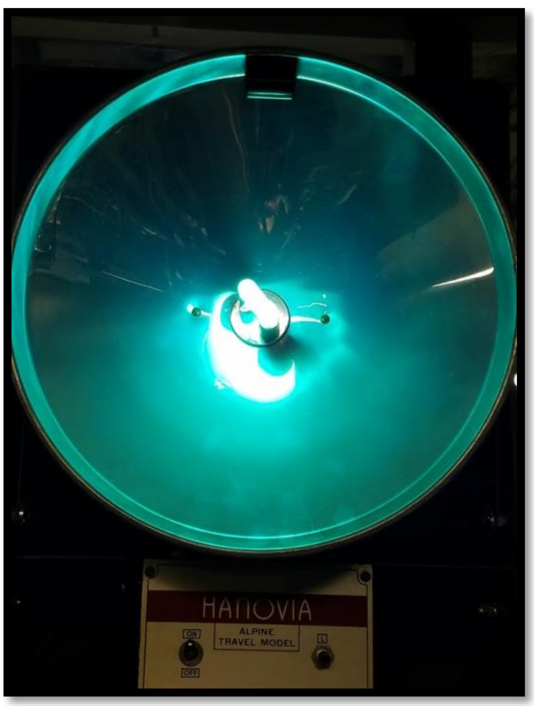
Burdick Ultraviolet Lamp with UVIARC bulb, Cooper Hewitt patents, (1920s)

E. J. Rose Cold Quartz Lamp (1930s)

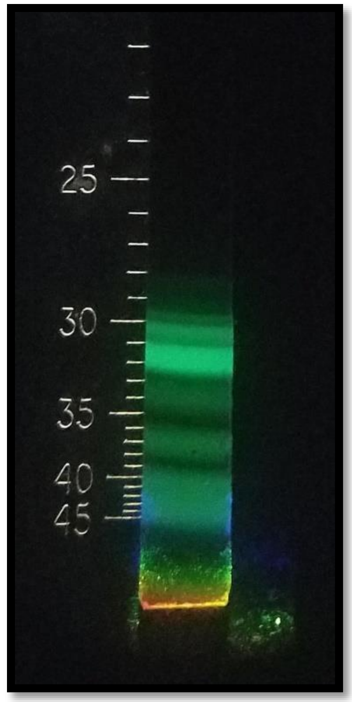


Sperti Portable Sunlamp (1920s)

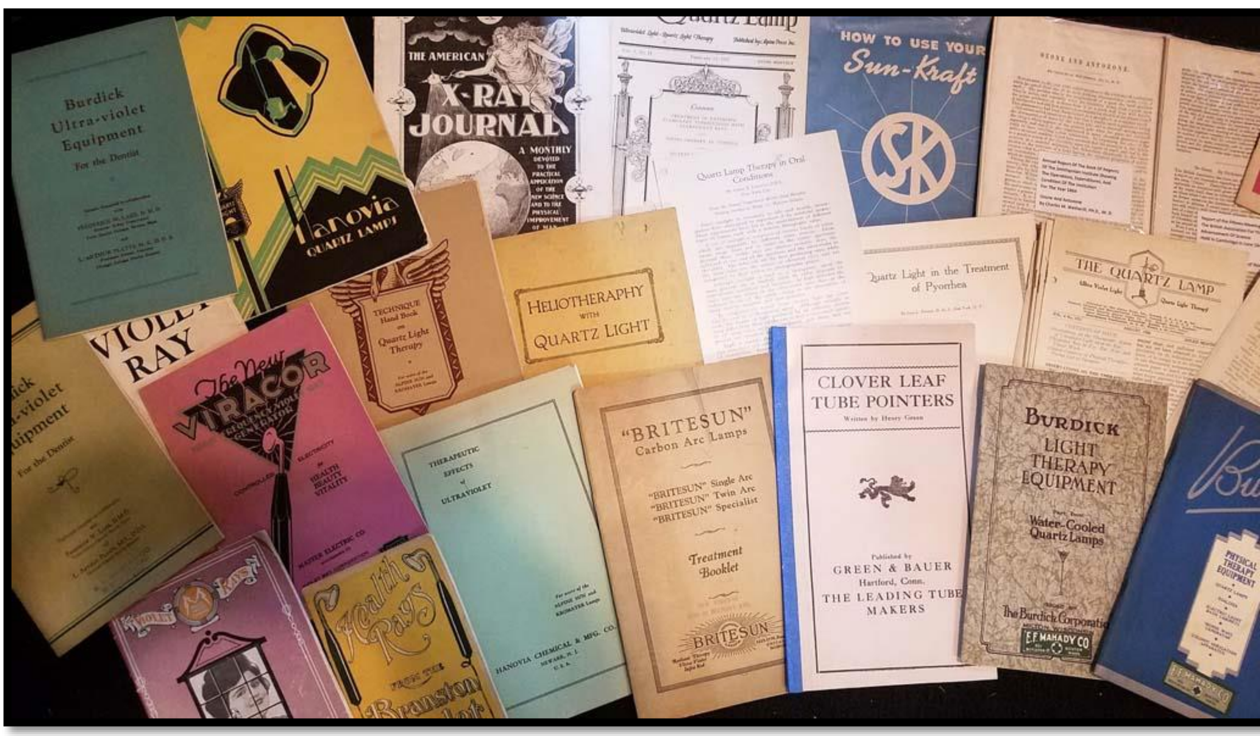
Sunkraft Cold-Quartz Ultra-Violet and Ozone Apparatus, electrodeless lamp, (1920s)



Hanovia Alpine Travel Model (1930s)



GE Sunlamp (1960s)



Examples of early instruction manuals and promotional booklets for ultraviolet lamps.

Glossary of terms used in the text:

Electromagnetic Spectrum: the range of wavelengths or frequencies over which electromagnetic radiation extends

Nanometer: a unit of length equal to one billionth of a meter

Angstrom: a unit of length equal to one hundred-millionth of a centimeter, 10^{-10} meter

Indigo: A dark shade of blue that has since been dropped from the name ROY G. BIV due to symantics of the 17th century

ROY G. BIV: A comical name used to help remember the color spectrum (RED ORANGE YELLOW GREEN BLUE INDIGO VIOLET)

Chemical Rays: Ultraviolet Radiation

Actinic Rays: 19th century word for Ultraviolet Radiation, meaning the ability to cause photochemical reactions

Heat Rays: Infrared Radiation

Wavelength: The distance between crests in an electromagnetic wave

Ozone: a colorless unstable toxic gas with a pungent odor and powerful oxidizing properties, formed from oxygen by electrical discharges or ultraviolet light. It differs from normal oxygen (O_2) in having three atoms in its molecule (O_3)

Vacuum Ultraviolet: Short wavelengths of Ultraviolet Radiation usually absorbed by oxygen in the air

Erythema: Reddening of the skin; sunburn

Photokeratitis: Sunburn of the eyes, a painful condition that causes temporary blindness

Carbon Arc: An early form of electric lamp where a high current intense white flaming arc is formed between carbon electrodes

Condenser Discharges: The rapid disruptive discharging of a capacitor, typically involving a high voltage and producing electrical oscillations of high frequencies

Leyden Jar: An early form of capacitor of small value capable of storing very high voltages

Quartz Glass: An extremely temperature-resistant glass that can transmit Ultraviolet Radiations

Corona Discharge: An electrical glow that occurs in the air around terminals charged to very high voltages

Spectroscope: an apparatus for producing and recording spectra for examination

Spectra: A band of colors as seen in the rainbow

Spectrograph: A picture showing spectra that when combined form a certain color of light

Ultraviolet: An invisible radiation that exists between X-Rays and visible light

About the author and museum:

Jeff Behary is curator of The Turn Of The Century Electrotherapy Museum, a 501(c)(3) Non-Profit organisation based out of South Florida. It is currently located within RGF Environmental Group, Inc. in Riviera Beach, FL where Jeff is employed doing Research & Development. RGF Environmetal Group, Inc. is a global leader in environmental technologies and provides the world with products that purify the air, water, and food without the use of harmful chemicals.

The Turn Of The Century Electrotherapy Museum is a collection of medical and scientific artifacts dating from the 1700s-2000s. In addition to the physical collection, the museum has been featured online with more than 125,000 files, located at ***electrotherapymuseum.org***. It has been the subject of many television shows and documentaries including History Channel's *Modern Marvels*, Travel Channel's *Mysteries At The Museum*, National Geographic's *American Genius*, Weather Channel's *Strangest Weather On Earth*, and numerous other programmes around the world in England, Germany, Canada, and Japan.

During 2020, the museum started an Internet Archive account where it's library is being scanned and uploaded in high resolution colour for free public access. It currently contains more than 250,000 pages of rare books, manuals, blueprints, research papers, and historical documents dating from 1600s-1900s. More information can be found at ***https://archive.org/details/@jeff_behary***

In 2023, the museum saved the last high voltage laboratory of the General Electric Company. With more than 45,000 pounds of equipment, the lab contained more than 1000 unpublished research papers and a 3 million volt Marx Impulse Generator dating from the 1939 World's Fair.

Jeff may be contacted at ***curator@electrotherapymuseum.org*** or by mobile at ***+1 561 267 2679*** with any questions or comments.