References

[1] Kraus, E. H., Seaman, W. A., and Slawson, C. B., Seamanite, a new manganese phosphoborate from Iron County, Michigan: *Am. Mineral.*, vol. **15**, p. 220, 1930.

[2] Gruner, J. W., Magnesiosussexite, a new mineral from a Michigan iron mine, isomorphous with sussexite and camsellite: *Am. Mineral.*, vol. **17**, p. 509, 1932.

[3] Gruner, J. W., *ibid.*

[4] Leith, C. K., Secondary concentration of Lake Superior iron ores: *Econ. Geology*, vol. **26**, pp. 282–3, 1931.

A COMPARISON OF ULTRA VIOLET SOURCES FOR PRODUCING FLUORESCENCE IN MINERALS

Richard L. Barrett, *Case School of Applied Science, Cleveland, Ohio.*

Abstract

The properties of several sources of ultra violet light are compared as to intensity and wave lengths. Curves giving the radiation characteristics of various sources, and the transmission characteristics of certain filters are included.

One of the most interesting and spectacular of the properties of minerals is displayed in the phenomenon of fluorescence. Recently interest in this subject seems to have been particularly stimulated by the introduction of new sources of exciting radiation capable of producing fluorescence in a variety of minerals. The writer has been interested in comparing the characteristics of the various energy radiating devices available for studying fluorescence, and it is believed that such a comparison should be useful to others who are interested in these phenomena.

There are three general types of radiant energy which have been used to excite fluorescence in minerals. Cathode rays, which consist of electrons moving at extremely high velocities, produce fluorescence in a number of substances, but there are a number of practical difficulties connected with their use. *X*-rays, which are electro-magnetic waves of very high frequency, cause fluorescence in a number of minerals, but devices for producing them are expensive and the number of minerals that respond to them is limited. The most spectacular effects of all are produced by ultra violet light, that is to say light of shorter wave length than the visible range. For practical purposes ultra violet includes all light from the limit of the visible spectrum at about 4000 A.U. down to 1600 A.U., which is the shortest wave length transmitted through air until we reach the region of the x-rays. The visible spectrum extends from about 4000 A.U. to about 7500 A.U.

Fluorescent minerals display very wide differences in the manner in which they react toward different sources of excitation. A certain specimen of willemite from Franklin Furnace, N. J., fluoresced strongly under ultra violet of all wave lengths from 3900 A.U. down to the x-ray region. Another specimen of the same mineral, from the same locality, did not respond at all to wave lengths longer than 3100 A.U., but fluoresced very brilliantly under shorter wave lengths including x-rays. A specimen of wernerite from Quebec did not respond at all to any wave lengths shorter than 2950 A.U., and showed its maximum response in the region of 3600 A.U. This wernerite responded rather feebly to a weak light source, but responded very strongly to a moderately intense source. On the other hand, certain fluorites respond strongly to quite weak sources.

There are at the present time five primary sources of ultra violet light which are useful in the production of fluorescence. They are the argon bulb, the high potential iron spark, the iron arc, the mercury vapor lamp, and the carbon arc fitted with special cored carbons. Of these the first two give off so little visible light that they may be used without a filter. The last three must be used with a suitable filter, which is either separate or incorporated in the lamp, which removes most of the visible light and incidentally much of the useful ultra violet. As a matter of fact none of these sources is ideal from all standpoints and each has its special advantages.

The most important characteristics of an energy source are the range of wave lengths available for producing fluorescence, and the intensity of the source within this range. There seems to be little advantage in increasing the intensity above a certain optimum value, but it is absolutely necessary to have suitable wave lengths available in order to get any effect at all. Curves are presented herewith which show energy distribution at different wave lengths for various ultra violet sources. These spectra actually consist of separate lines but for convenience in representation are drawn as smooth curves. The curves do not show the relative intensity of the various sources because the differences in intensity are too great to be satisfactorily represented by curves to scale. A table giving a comparison of intensities is presented later in this paper. Curves are also given to show the transmission characteristics of certain filters which may be used to screen out visible light which would otherwise obscure the fluorescent effect. Unfortunately the best available filters transmit a rather limited range in the ultra violet. These curves used in conjunction with the table of intensity comparisons will enable the reader to evaluate the properties of any of the sources mentioned.

The argon bulb is a gas discharge tube similar in principle to the familiar neon sign tube, except that it is filled with argon and operates on the ordinary 110 volt circuit. It produces wave lengths in the long ultra violet region which are limited in the short wave lengths by the ability of the glass bulb to transmit short waves. The intensity is very low, being only about 1/2000 that of a suitably filtered quartz tube mercury lamp. However, it is cheap and easily available and produces striking effects in a number of minerals.

The term iron arc is properly applied to a low voltage arc between iron electrodes. However, mineralogists have been in the habit of using the term to refer to the high potential disruptive spark between iron electrodes which has been a popular source of ultra violet. The apparatus for producing the iron spark consists of a step-up transformer delivering about 4000 volts, a suitable condenser, and a pair of adjustable iron electrodes. As shown on the curve the iron spark produces a peak at about 2600 A.U. and is quite weak in the long ultra violet. An apparatus rated by the manufacturer at 200 watts gave about 60 times the intensity of the argon bulb. The rather large amount of visible light could not be filtered out to good advantage because available filters shut out much of the particular part of the spectrum in which the iron spark is richest. A true iron arc may be operated on direct current with about 50 volts across the arc and drawing in the neighborhood of 5 amperes. It cannot be satisfactorily operated on alternating current. It produces a considerably higher intensity than the aforementioned iron spark device but the amount of visible light produced is so great that a filter is indispensable. However, the intensity even with the filter is about twice that of the iron spark. The iron spectrum is particularly useful because of its richness in the shorter ultra violet region which produces fluorescence in a number of minerals which do not respond to most other sources. The iron spark has the particular advantage that one may dispense with a filter.

The carbon arc using special cored carbons (type "C" furnished by the National Carbon Co.) is capable of producing very powerful radiations throughout the ultra violet region. Its spectrum is strongest in the near ultra violet region but is amply powerful

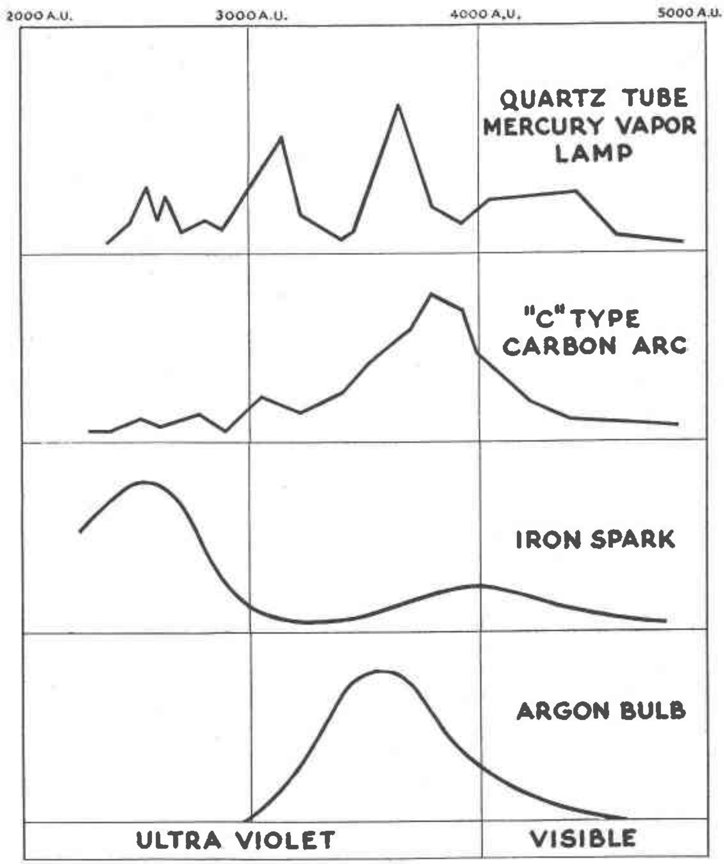

Fig. 1. Curves showing the spectra of ultra violet sources.

down to the limit of the transmission of available filters. A very large amount of visible light and a great deal of heat are also liberated. It is of course necessary to filter out the visible radiation, Corning No. 986 being the best available filter. The disadvantages are the heating effect which is likely to break the filter and the necessity for keeping the arc in adjustment. An arc consuming 11 amperes at 50 volts across the arc furnishes satisfactory strength. If greater intensity is desired one may simply use larger carbons and greater current.

Mercury vapor lamps furnish a very powerful and convenient source of ultra violet. The visible light is so strong however that it must be filtered out by some means. If glass is used for the tube in which the arc operates, the short ultra violet is of course absorbed by the glass. The most efficient device is the mercury arc in a fused quartz tube. If filtered with the Corning No. 986 filter it furnished powerful radiations as low as 2530 A.U. in wave length which includes the range in which most minerals fluoresce. The disadvantage is the high cost of the quartz tube lamp.

There are now available two types of mercury vapor lamps in which the enclosing tube is made of special nickel-cobalt glass which eliminates most of the visible light except just within the limit of the visible spectrum. Unfortunately this glass also cuts out nearly all of the radiation shorter than 3100 A.U. and there are quite a number of minerals that respond only to radiations beyond this range. One type of lamp embodying this principle is a regular Cooper Hewitt tube 22 to 50 inches in length as desired (manufactured by the General Electric Co. and sold under the name NiCo lamp) which operates at from 250 to 450 watts. This provides radiation of ample intensity within the range of transmissibility of the nickel cobalt glass used and while the wave length range is limited it is probably the best instrument available for museum use because of its convenience. Another somewhat similar device is a mercury vapor bulb (manufacturered by Westinghouse Lamp Co. and sold under the name Black Bulb) containing a heating filament, and similar to the bulbs used in certain types of "sun lamps" used in homes, except that instead of clear glass the bulb is made of nickel-cobalt glass. The wave length range is the same as that of the device just mentioned but the power consumption for the five ampere lamp is only 85 watts and the intensity is necessarily lower.

There are a number of different glasses available which are capable of filtering out most of the visible light and at the same time letting through some of the ultra violet.[1] Of these the trans-

[1] W. S. Andrews in an article called "An Apparatus for Separating Visible From Invisible Light" in the *General Electric Review*, October, 1917, suggested a very interesting method for separating out the visible light from the iron spark radiation

mission curves of three types are here given. The best of the available filters is no doubt the Red Purple Corex A No. 986, manufactured by the Corning Glass Works. This filter transmits ultra violet down to 2500 A.U. wave length and passes only a small range in the blue end of the visible spectrum. It does transmit also a small band in the extreme red (not shown on the curve), but

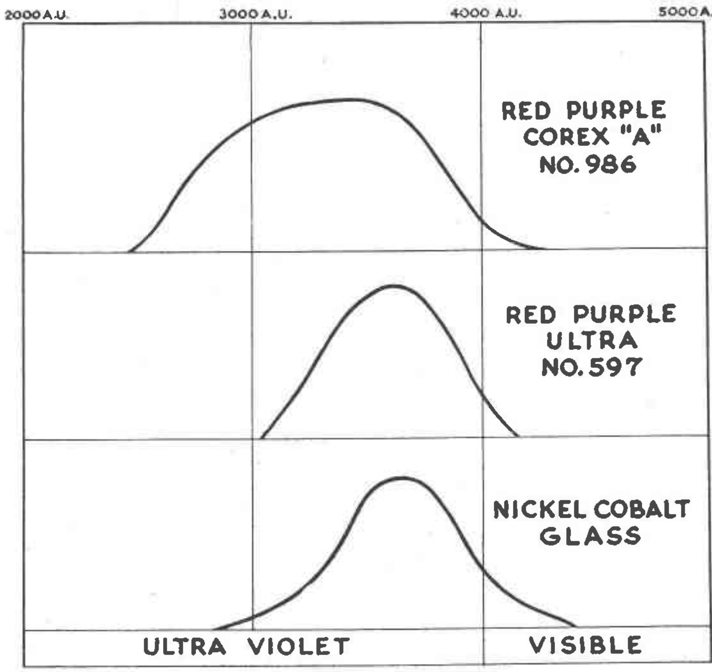

Fig. 2. Transmission curves of ultra violet filters.

this does not detract from the effects especially when used with the quartz tube mercury lamp which is weak in the red end of the spectrum. This filter is rather expensive and is very liable to breakage. It is non-heat-resisting and has low mechanical strength. However, if care is taken to avoid over heating it is very satisfactory. Corning Glass Works' Red Purple Ultra No. 597 transmits a much more restricted range of wave lengths, but it is less expensive and has superior mechanical properties. The curve is also

which might interest some readers. His device makes use of dispersion through a quartz lens.

given for the Nickel-Cobalt glass used for the tube in special types of mercury vapor lamps. Its range is nearly the same as that of the Corning No. 597 but it transmits somewhat more visible light. Jenaer Glaswek, Schott und Gen., Jena, Germany, manufacture a filter, type UG2, which transmits wave lengths from 4000 A.U. down to about 2850 A.U., according to their catalog. The curve for this glass is not included but it is mentioned for the convenience of European readers. The characteristics of all these glasses vary from batch to batch but the curves are believed to be representative.

The following comparisons of intensity were made by illuminating a ground quartz disc by a given source at a standard distance. The disc was then photographed using a pin hold for a lens and the density of the silver deposit on the film measured on a microphotometer. The time of exposure required to produce a definite density of image for the different sources was used as a measure of the relative intensity. The intensity of all these sources is somewhat variable under different conditions and while the comparisons are not exact it is believed that they are within the range of variation of the various sources.

Source	Relative Intensity
Quartz tube mercury vapor lamp, 4.6 amperes at 60 volts D.C. across the arc, filtered through Corning No. 986 Red Purple Corex A.	1000
Same as above Filtered through Corning No. 597 Red Purple Ultra.	600
Bulb type mercury vapor lamp (Black Bulb), 5.2 amperes at 16 volts A.C. made of nickel-cobalt glass.	45
Tube type mercury lamp (NiCo Lamp), with nickel cobalt glass tube. Rated 385 watts D.C. or 450 watts A.C.	300–350 (estimated)
Carbon arc, 12 amperes at 40 volts A.C. across the arc. Eveready "C" type carbons and Corning No. 986 filter.	500
Same as above, Filtered through Corning No. 597 filter.	360
Iron arc, 5 amperes at 45 volts D.C. across the arc, Corning No. 986 filter.	30
Iron spark, Rated at 200 watts, 4000–5000 volts, no filter.	15
Argon bulb, Rated at 2 watts A.C., no filter.	0.25

To summarize one may say that either a quartz tube mercury lamp or a carbon arc with "C" type carbons, combined with the Corning No. 986 filter, is the most generally useful ultra violet source because they combine high intensity with a great range of wave lengths. The mercury lamp with nickel-cobalt glass tube is desirable in museums because of its convenient form and freedom of adjustments. The iron spark still furnishes a convenient source of the very short wave lengths although the intensity is rather low. The argon bulb is recommended within its limits because of its convenience and cheapness.

ACKNOWLEDGMENTS

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