THE PHYSICAL CHARACTERISTICS OF X-RAY FLUORESCENT INTENSIFYING SCREENS.[1]

By Millard B. Hodgson.

THE use of fluorescent screens for the intensification of exposure is of widespread practice and of considerable importance in practical x-ray photography or roentgenology. Lately, in the work of Hull, St. John and others, the fluorescent screen has been employed to reduce the lengthy exposures of such x-ray spectroscopic investigations that are dependent on the photographic plate for record.

In spite of the general use of these screens in quite a variety of work, very little has been done in the study of the fundamental laws of such a system. Shearer,[2] Edwards,[3] Baker[4] and others, however, have contributed excellent papers to the general fund of knowledge from a strictly utilitarian standpoint. Recently Sheppard[5] advanced some interesting theories regarding conditions for the fluorescent state.

It is the purpose of the present paper to outline briefly the results of some experiments introductory to a general study of fluorescence to x-rays.

In dealing with fluorescent phenomena dependent on an x-ray tube for excitation, there are two types to be considered, both of which may be utilized for photographic intensification. The first type is that of true characteristic radiation, the second vultra-violet and visible fluorescent radiation. The true characteristic radiations of all the elements which are feasible to use are within that range of frequencies usually termed x-rays. Hence, the laws pertaining to high frequency radiation govern the photographic use of screens dependent on this principle. In the case of fluorescent emission of ordinary light, the laws of ordinary optics apply. The emitted radiation also seems no longer fundamentally dependent on the atom alone but on the space lattice pattern of the crystal system of the particular fluorescent solid used.

Of these two types of intensifying screens the second has proven the far more efficient in practical usage.

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[1] Communication No. 67 from the Research Laboratory of the Eastman Kodak Company.

[2] J. S. Shearer, American Journal of Roentgenology, February, 1914.

[3] H. T. Edwards, American Journal of Roentgenology, December, 1916.

[4] H. Thorne Baker, Journal of the Roentgen Society (British), October, 1917.

[5] S. E. Sheppard, Illuminating Engineer (London), June, 1917.

Herschel, Stokes, Wood, Wiedeman, and Nichols and Merritt have contributed chiefly to the general subject of fluorescence within the ordinary range of frequencies usually called light. Of these Nichols and Merritt have perhaps done the most complete quantitative work.

The investigation of the phenomena of fluorescence of materials to x-rays, however, has not been as yet thoroughly investigated.

Of the materials which fluoresce to x-rays in the range of frequencies from the ultra-violet to the red, there are only a few which can be used efficiently for photographic intensification. All of these substances must be in the crystalline state. Barium-platino-cyanide, barium salicylate, calcium tungstate, molybdenum tungstate, magnesium tungstate and some double tungstates of these metals fluoresce to a greater or less extent to x-rays and the radiation is more or less active photographically. Of these, crystalline calcium tungstate is by far the best, with present photographic x-ray materials. The salt is usually powdered and coated with a suitable binder on a support of some material of slight x-ray absorption, such as cardboard or celluloid. This screen is then placed in contact with the photographic surface and exposure made through either the screen or the photographic plate or film.

The efficiency of any radiator as a source of photographic stimulation depends primarily on the comparative spectral distribution of the energy of the radiator and the spectral sensibility of the particular photographic plates used. While these relations have not been determined as yet on an equal energy basis for x-ray materials, qualitative analyses have been made.

In Fig. 1 are shown the spectral sensibilities to white light of an (*a*) x-ray plate, (*b*) a fast ordinary plate, (*c*) an orthochromatic plate and (*d*) a panchromatic plate.

The fluorescent spectra of calcium tungstate have been studied under the following conditions. The screens used were commercial types. Spectra were obtained using a Hilger quartz spectrograph on Seed X-Ray, Seed 30 and Wratten Panchromatic Plates. The illustrations shown were made on Seed 30; the spectral distribution of photographic energy in the fluorescence does not, however, extend appreciably further toward the red than shown on these photographs. The screen was placed immediately in front of the slit and the x-ray tube in front of the screen as shown in the diagram (Fig. 2). A Coolidge tube of medium focus was used, the length of exposures averaging 1,000 milliampere minutes at 8 in. distance from the target to the screen. The photographic plate was carefully shielded from stray radiation during the long exposures, which in some cases were for 24 hours.

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PLATE I.
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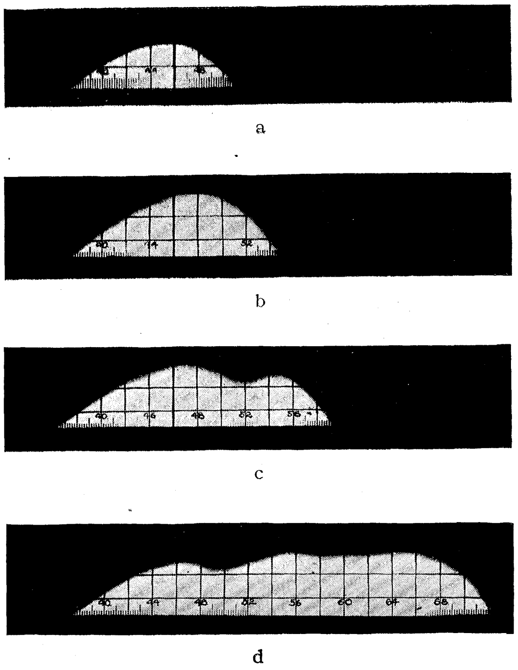
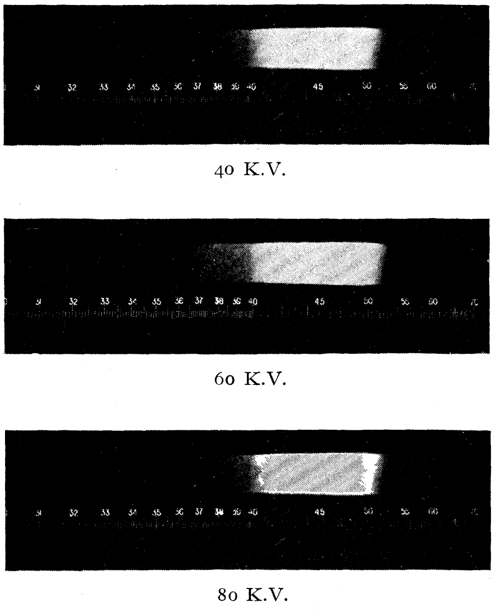


FIG. 1.



40 K.V.

60 K.V.

80 K.V.

FIG. 3.

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Spectrograms were made with the tube operating at 40 K.V., 60 K.V. and 80 K.V. (R.M.S.). These are illustrated in Fig. 3, losing, however, by reproduction. It will be noticed that there is a rather abrupt jump from a continuous or at least a broad-banded spectrum to a relatively narrow band spectrum at 80 K.V. It is a significant fact that at 80 K.V. the α and β lines of the K series of tungsten begin to be noticeable in the primary x-ray spectrum of the tube used. Below this voltage, the variation of intensity of the tungsten spectrum with wave-length is a smooth curve, being practically continuous except for the "L" lines which however seem to exert but slight influence on the fluorescence of calcium tungstate. This suggests some peculiar resonance phenomena taking place when the electronic orbits are selectively "stirred" by the incident radiation reaching a certain critical frequency.

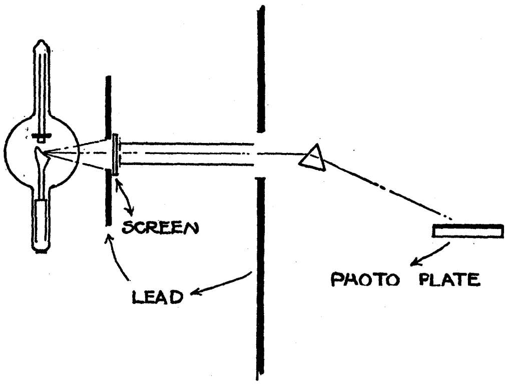


Fig. 2.

The fluorescence is certainly primarily dependent on the following factors: (1) selective absorption of the elements of the crystalline compound present in the intensifying screen, (2) the frequency of the exciting radiation, and (3) the crystal structure of the particular calcium tungstate used. The x-ray analysis of the crystal structure of calcium tungstate will probably throw a great deal of light on the subject.

A comparison of the curves in Fig. 2 with the spectra in Fig. 3 will enable one to pick out the plate most efficient for use with the screen. However, in a final consideration of efficiency the sensitiveness of the material to the direct x-ray beam must be given weight. It has been found that in a negative made from a screen system, about 20 per cent. of the exposure is due to the absorbed energy of the direct rays, the remaining 80 per cent. being supplied by the screen fluorescence. Hence to decide the maximum efficiency in the case where the ratios of screen fluorescence and plate spectral sensibility are the same for two photographic materials, their relative sensitiveness to x-rays alone should be considered.

As to technique of using a screen, the best practice is to expose through the support of the emulsion which is in contact with the surface of the fluorescing screen. Hence it follows that the support must be one of minimum opacity to x-rays. In the case of two emulsions of equal sensitiveness, one on glass and the other on transparent, flexible base (film), the latter support should be used, being more transparent to x-rays.

This support has the further advantage of permitting bending which is to be desired in some spectroscopic experimental work. In the precise determinations of high frequency wave-lengths, however, it will be the better policy to use emuslion coated on plane surfaced glass. Computation shows that the error involved in a wave-length determination on film, due to shrinkage of the support, may be as high as one per cent. of the wave-length.

As may be seen from the spectra in Fig. 2, the output of radiant energy photographically suitable increases with voltage. It also increases with current to a saturation value, dependent on the particular screen used. The limiting voltage, however, which it is permissible to use in practical radiography, is governed by the absorption of the object radiographed. That is, in the case of the average picture of body parts, in order to absorb enough of the incident x-ray beam to differentiate fine detail the penetrating ability of the beam should be of a certain minimum value, of necessity limiting the tube voltage.

In spectroscopic investigation, for instance, in crystal structure determination by the Hull method, penetration is of no great consequence. The resolving power of the system, however, greatly decreases with increased voltage, due to the penetration and scatter of the shorter wave-lengths in the screen.

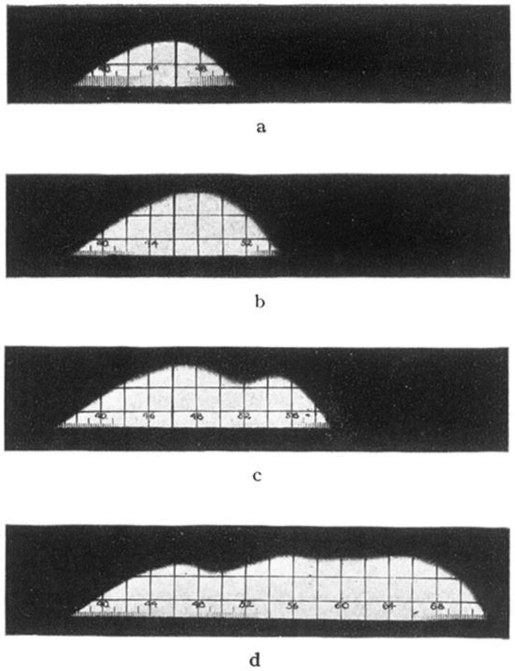
In the recording of the shorter wave-lengths of x-rays such as used in the radiography of castings or welds, in view of the great penetrating power of the rays, the photographic plate fails to absorb sufficient energy to give a picture permitting of clear interpretation. In these cases the usual calcium tungstate screen, while fluorescing, causes a grainy deposit. The writer in trying to shorten such exposures has tried using the characteristic radiation from metal screens.

Silver, copper, lead, tungsten and platinum have been used. Of the materials tried silver and platinum were the most practical and efficient. A sheet of silver .2 mm. thick gave an intensification under the standard conditions used of 100 per cent. Platinum, used economically in the form of a cathodically sputtered plane mirror, of a film thickness of less than .001 mm. gave an intensification of 20 per cent. These per cent. differences while seemingly small in average photographic practice where the exposure is a matter of seconds, become relatively large when one considers running an x-ray tube minutes and hours for a single exposure. The use of such screens does not involve any increase in graininess.

Summary.

1. The fluorescence of various materials to x-rays has been discussed from the point of view of photographic efficiency.
2. The spectral distribution of the fluorescence from calcium tungstate has been qualitatively determined and has been found to extend further into the ultra-violet as the voltage applied to the exciting tube increases.
3. The photographic efficiency of the characteristic radiation from silver, tungsten, platinum and lead has been approximately determined for certain photographic materials and found to be of practical value.

Research Laboratory,
Eastman Kodak Company,
May 6, 1918.



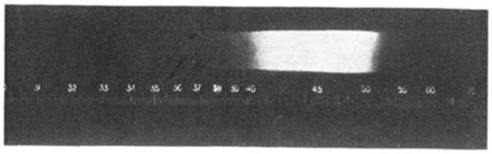
a

b

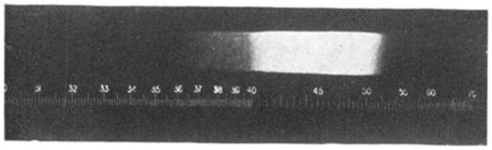
c

d

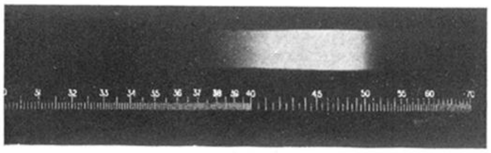
FIG. 1.



40 K.V.



60 K.V.



80 K.V.

FIG. 3.