THE LUMINESCENCE OF DIAMOND EXCITED BY X-RADIATION

By G. N. Ramachandran

(*From the Department of Physics, Indian Institute of Science, Bangalore*)

Received May 18, 1946

(Communicated by Sir C. V. Raman, Kt., F.R.S., N.L.)

1. Introduction

Diamond can be made to luminesce in a variety of ways, *e.g.*, by irradiating with ultra-violet rays, cathode rays or X-rays or by the action of heat or friction. The fluorescence spectra and various other properties associated with fluorescence, such as the local variations of colour and intensity, have been studied by a number of workers in this laboratory using ultra-violet excitation (Nayar, 1941; Mani, 1944, 1945; Sunanda Bai, 1944; Rendall, 1946). John (1930) has reported a study of the fluorescent spectrum when exposed to cathode rays. The present paper describes the investigations made by the author on the fluorescence of diamond when irradiated with X-rays. Among the various phenomena that were studied may be mentioned the fluorescence spectra, the fluorescence patterns, the correspondence or otherwise of these with those produced by ultra-violet excitation and the influence of the hardness and intensity of X-rays on the intensity of luminescence. A discussion is also included on the probable mechanism by which the luminescence is produced by the impact of X-rays.

2. Colour and Intensity of Luminescence

The luminescence of diamond under X-ray irradiation is much weaker than that under ultra-violet irradiation. The X-ray tube was generally run at 10 to 15 milliamperes with a peak voltage of 35 K.V. Preliminary observations showed that increasing the voltage applied to the X-ray tube remarkably brightened up the luminescence. Consequently, voltages up to 50 K.V. were used for feebly luminescent diamonds. A tungsten target was used in the X-ray tube to have a high efficiency of production of X-rays.

Visual observation with a large number of diamonds showed that the colour of luminescence in X-rays generally followed the colour as seen in the ultra-violet. The diamonds which fluoresced blue in ultra-violet rays were also blue in X-rays, but the colour in X-rays had less of violet in it. The colour was blue to blue-green. Similarly, diamonds fluorescing green in ultra-violet also showed a green colour in X-rays. The so-called nonluminescent diamonds which emitted practically no light in ultra-violet rays were definitely luminescent in X-rays, although the luminescence was very feeble. The colour could not be fixed definitely on account of the extreme feebleness, but appeared to be blue to blue-green.

A striking fact that was obvious even on visual observation was that the range over which the intensity of luminescence varied from specimen to specimen with X-ray irradiation was much smaller than with ultra-violet irradiation. This phenomenon was demonstrated in a qualitative manner by a series of photographs taken by the author and published in a paper by Sir C. V. Raman on the "Nature and Origin of Luminescence in Diamond" (Raman, 1944). The photographs were taken with a jewel containing a large number of diamonds which were known to fluoresce in ultra-violet rays with intensities varying in the ratio of about 1 : 1000. (Photographs illustrating this fact were also reproduced in Sir C. V. Raman's paper quoted above). With X-rays, the maximum range was certainly not more than 1 : 50. This phenomenon was quantitatively studied in a particular case of a purely blue-fluorescent diamond (N.C. 100) which showed patches of luminescence, which were sensibly uniform in intensity, but whose intensities were different. Since the diamond was of uniform thickness, complications due to differences in thickness did not arise. The diamond had at least three distinct areas whose intensities of luminescence were different (see Fig. 6), which may be designated by A, the central bright patch, B, a small extension of this triangular patch to the right and C, the feebly luminescent surrounding area. The relative intensities of luminescence of these three areas were determined by photographic photometry. An absorption cell of a solution of sodium nitrite in water was always kept in front of the camera to absorb the ultra-violet rays scattered by the diamond. This cell was also kept when photographing the luminescence excited by X-rays, so that the comparison of intensities was restricted to the spectral region of luminescence in the visible. The results of photographic photometry gave intensity ratios of 12 : 5·0 : 1 with ultra-violet excitation, while with X-rays it was only 2·5 : 1·6 : 1. The interpretation and explanation of this fact will be taken up in a later section.

3. LUMINESCENCE PATTERNS OF X-RAY LUMINESCENCE*

All diamonds which exhibited patterns of luminescence when excited by ultra-violet rays were found to exhibit patterns under X-ray excitation

---

* Hereafter, by the term 'X-ray luminescence' will be meant the luminescence under X-ray excitation, and similarly 'ultra-violet luminescence' will mean the visible luminesence excited by ultra-violet rays.

also. The patterns were photographed with some diamonds. The technique was very simple. The diamond was kept in a light-tight box, one side of which was closed by black paper, through which X-rays were incident. The diamond was kept at an angle of about 30° to the X-ray beam and the pattern was photographed with a camera whose axis was kept normal to the diamond plate. An examination of the appearance of the patterns in the focal plane of the camera confirmed the fact that the colour of the luminescence with X-rays is very much the same as with ultra-violet rays. The luminescence patterns observed were also found to be remarkably similar to those in ultra-violet luminescence. Hence, only a small number of photographs were taken to illustrate the patterns. These are reproduced in Figs. 5 and 6 in Plate VIII. No attempts were made to separately photograph the blue and yellow luminescence patterns by the use of filters, as even the total luminescence took many hours to photograph and since the resemblance of these to the corresponding patterns in ultra-violet luminescence was so striking. However, it was found that the X-ray luminescence patterns were less contrasty than the ultra-violet luminescence patterns of the same diamond. This will be evident on comparing the X-ray luminescence pattern of N.C. 100 (Fig. 6) with the corresponding ultra-violet luminescence pattern reproduced in a paper by Rendall (1946) in this symposium. The origin of the difference must be found in the result described in the preceding section, namely that the ratio of intensities of luminescence had a much smaller range when X-rays are used than when ultra-violet rays are used. The same phenomenon was also observed with other diamonds.

It was observed that if the diamond plate was kept very nearly parallel to the X-ray beam so that the X-rays entered it at grazing incidence, then the details in the luminescence pattern became very much clearer and sharper than otherwise. This will be evident from Fig. 5 which is the luminescence pattern of N.C. 118 using X-rays falling at an angle of 5° on the diamond. If one compares it with the corresponding pattern in ultra-violet light (reproduced as Fig. 10, D. 198 in Sir C. V. Raman's paper quoted earlier), it will be seen that the X-ray luminescence pattern is by far the clearer and the sharper of the two. The origin of this sharpening must be traced to two causes. Firstly, the bands of bright luminescence in diamond are generally found to be located in fairly narrow laminæ parallel to the octahedral planes (Ramachandran, 1946). In diamonds of octahedral cleavage, these laminæ do not run normal to the surface of the diamond, so that if the whole thickness of the diamond is luminescent, the luminescence pattern becomes somewhat confused when viewed normally. The second fact to be considered is that the luminescence with X-rays is largely caused by the soft components which are absorbed in a relatively small distance from the surface. The proof of this fact will be given in the next section. Therefore, when the diamond is kept obliquely to the X-ray beam, the intense part of the luminescence is confined to a thin layer near the front surface, and the confusion arising in the pattern due to overlapping is avoided. The pattern thus comes out sharp and clear.

As already remarked, diamonds which do not luminescence in ultraviolet light are definitely luminescent in X-rays. The intensity is very small, about one-twentieth of the weakest blue-luminescent diamond, but it can be seen clearly. In Fig. 6 the X-ray luminescence pattern of such a diamond (N.C. 60) is reproduced. It will be seen that there is little variation in intensity. The bright lines near the corners are due to bevelled edges, and the series of rings near the centre are interference fringes produced at the contact between the diamond and the plate on which it was kept.

4. EFFECT OF THE QUALITY AND INTENSITY OF X-RAYS ON THE INTENSITY OF LUMINESCENCE

The influence of the applied voltage and the current through the X-ray tube on the intensity of fluorescence was investigated by photographic photometry. All the photographs were taken with the same exposure time, and no assumptions were made as to the approximate validity of the reciprocity relation. The time of development and other factors were carefully controlled. The diamond employed for the investigation was N.C. 73, which exhibited uniform blue luminescence. The density of the photographs was measured by a Moll microphotometer and the standards were obtained by varying the aperture of the camera. The results of the studies are given in Tables I to III below, which give respectively the effect of current and voltage applied to the X-ray tube and the effect of interposing aluminium filters of known thickness.

TABLE I

Effect of current through the X-Ray tube on the fluorescence intensity. Applied peak voltage 45 K. V.

Current m. amp.	Intensity of fluorescence in arbitrary units
1·0	1·0
2·5	2·4
5·0	5·1
8·0	7·9
10·0	10·0

TABLE II

Effect of the voltage applied to the X-Ray tube on the fluorescence intensity. Current 5 m.amp.

Peak voltage in K. V.	Fluorescence intensity I in arbitrary units	Log I
52·5	16·6	1·22
45·0	7·4	0·87
37·5	5·5	0·74
30·0	3·2	0·50
22·5	1·6	0·21
15·0	0·27	$\bar{1}$·44

TABLE III

Effect of interposing aluminium foils in the X-Ray beam on the total intensity of fluorescence I of the diamond. Applied peak voltage 35 K. V.

Thickness *t*	I	Log I
mm.		
0·0	5·0	0·70
0·2	2·2	0·34
0·4	1·35	0·13
0·55	1·0	0·00

It will be seen that the intensity of fluorescence varies linearly with current over the range of intensities studied. It may be remarked that the absolute intensity was very much smaller than that excited by ultra-violet light, so that such an accurate linearity is to be expected. The photometry confirms the visual observation that an increase in the applied voltage has an appreciable enhancing influence on the fluorescence intensity. It will be seen that, in the range 25 to 50 K.V., an increase in peak voltage of 7·5 K.V. nearly doubles the intensity of fluorescence. If log I were plotted against the logarithm of the voltage, it will be found that the resulting curve is nearly a straight line with a slope of about 3, so that the fluorescence intensity varies roughly as the cube of the voltage. This will be considered in greater detail in a later section. The results in Table III are very interesting since they throw much light on the relative capacities of X-rays of different wavelength to excite fluorescence in diamond. The fact that the intensity is reduced to less than half by the interposition of only 0·2 mm. of aluminium, which transmits more than 60% of all wave-engths below 0·9 Å.U., shows that components softer than this play a predominant part in exciting the fluorescence. This point is considered in greater detail in a later section where quantitative formulæ for the intensity of luminescence are developed.

In order to confirm this fact, namely that most of the fluorescence is excited by soft X-rays, the following experiment was conducted. A diamond (N.C. 71) which had a long straight edge was kept with this edge facing the X-ray tube and in such a way that the X-rays passed exactly parallel to the broad sides. In this way, the X-rays which excited the fluorescence entered through the edge over an area defined by the length and thickness of the crystal and proceeded inwards along its breadth. If the diamond were viewed in a direction at right angles to the X-rays, a shading away of the luminescence from the front edge inwards was observed, as was expected. The softer components of the X-rays were completely absorbed within the first millimetre or so, and the luminescence was very bright near the front edge. As the X-rays progressed inwards they became harder and harder so that the intensity of luminescence steadily decreased. The phenomenon was photographed and the photograph is reproduced in Fig. 7 (*a*), Plate IX. To further confirm the idea, aluminium foils of different thickness were introduced between the diamond and the X-ray tube. It was then observed that the intensity of luminescence fell down progressively, as was to be expected from the results described in the previous para. But what was more interesting was the fact that the fading away of the luminescence from the front surface inwards was also less and less prominent. These are illustrated by Figs. 7 (*a*) to (*d*), which were taken with aluminium foils of thicknesses 0·0, 0·1, 0·2 and 0·55 mm. interposed. The exposure times were 1 hr., 2 hrs., 4 hrs. and 8hrs. in order to obtain approximately the same initial intensity at the front edge. It will be seen that the fall of the luminescence intensity is less and less prominent as one passes from Fig. 7 (*a*) to (*d*). The corresponding microphotometric traces are also reproduced in Fig. 1 which show very clearly that the rate of falling away of the intensity of fluorescence is smaller when the incident X-rays are made harder. Also, a study of the slope of the microphotometric traces at different distances from the front edge shows that this also becomes smaller and smaller as one goes away from this edge. The reason for this becomes clear if one notes that the softer X-rays are also absorbed by the diamond, so that the X-ray beam becomes harder as it progresses into the crystal, and is consequently absorbed less. The quantitative calculations are reserved to a later section.

The falling away of the intensity of luminescence as the X-rays penetrate the crystal was visually observed also with N.C. 60, a diamond of the ultra-violet transparent variety.

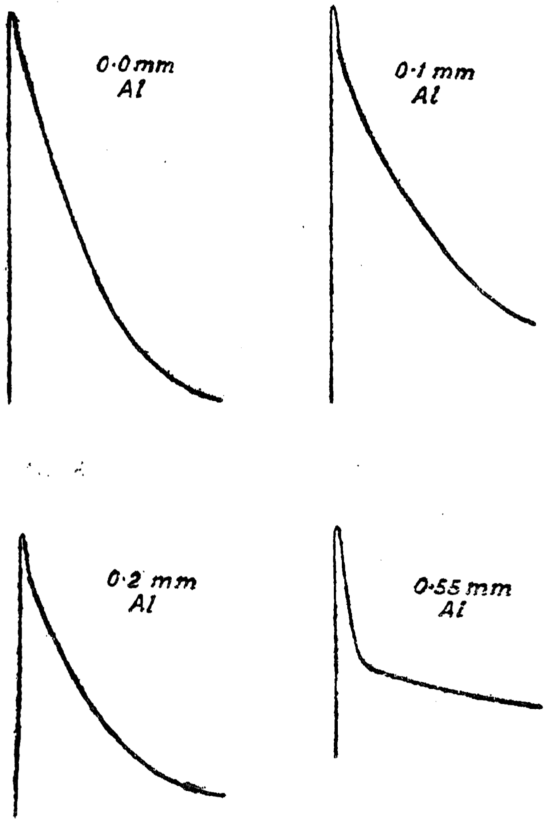


FIG. 1. Microphotometric traces of the fall of fluorescence intensity. These were copied from the original traces to facilitate reproduction as line blocks

5. X-RAY LUMINESCENCE SPECTRUM OF DIAMOND

Since the luminescence of diamond under X-ray irradiation is extremely weak, a study of the spectrum was made with a fast spectrograph of small dispersion. A somewhat detailed study has been made only with one diamond, N.C. 68, which is intensely blue-luminescent when excited by ultraviolet rays. In X-rays, it was weakly luminescent, so that long exposures had to be given to obtain the spectrum. An idea of the relative intensities in the two cases may be obtained from the fact that while 5 minutes sufficed to give a strong spectrum in the former case, an exposure of 20 hours was necessary to get a moderately strong spectrum with X-rays. The two spectra have been taken side by side with a Hartmann diaphragm and are reproduced in Fig. 8. These were taken at room temperature. A comparison of the two spectra shows that, on the longer wave-length side of the principal electronic line at 4156 Å.U., the spectrum is essentially the same in both the cases, namely consisting of four emission bands with maxima at 4278, 4387, 4514 and 4643 Å.U. The intensity of the bands are, however, different in the two cases. The spectrum of the X-ray luminescence in this region appears as though the emission bands are superposed on a continuous spectrum. The most interesting fact that comes out of the comparison of the two spectra is that, while the 4156 line itself comes out as an *emission* line in ultra-violet fluorescence, it occurs as an *absorption* line in X-ray fluorescence. Also, there is an extension of the spectrum to the shorter wavelength side of 4156 Å.U. in X-ray fluorescence, which is absent with ultra-violet excitation. This extension occurs as a continuous spectrum, in which the absorption bands occur with maxima of absorption at 4041, 3950 and 3850 Å.U. The continuous spectrum extends upto about 3600 Å.U. These details can be seen in Fig. 8, Plate IX. The spectrum of X-ray luminescence can thus be described as a combination of the absorption and the ultra-violet luminescence spectra. It is a continuous spectrum, on which the absorption of diamond acts for wavelengths smaller than and including 4156 Å.U. and on which is superposed the ultra-violet fluorescence bands for longer wavelengths.

That this description is essentially correct is shown by a study of the two spectra given by a weakly blue-fluorescent diamond, N.C. 73. The ultra-violet fluorescence spectrum of this diamond is exactly similar to that of N.C. 68, except for the fact that the whole spectrum is fainter. The X-ray luminescence spectrum, on the other hand, is strikingly different. It consists of a continuous spectrum running from about 3600 to 5000 Å.U. with just a hint of an absorption line at 4156 Å.U. The continuous spectrum was recorded with nearly the same exposure as was required for N.C. 68 (*viz.*, 20 hours), but no quantitative estimate was possible since the two diamonds had very different sizes and shapes. Since this diamond (N.C. 73) was feebly absorbing in the near ultra-violet, the absorption bands did not occur in the spectrum. It thus appears as though X-rays give rise to a continuous spectrum in all diamonds of the blue-fluorescent class, and in addition give rise to the characteristic fluorescent bands with an intensity proportional to the intensity of ultra-violet fluorescence. This idea fits in qualitatively with the results obtained for the two diamonds described above. For instance, it explains why the bands in the X-ray fluorescence spectrum are less clear than in the ultra-violet fluorescence spectrum with N.C. 68 and why they are absent in that of N.C. 73.

A more quantitative verification of this idea is obtained in an entirely different manner, namely from the results described in section 2, in particular the values for the relative intensities of luminescence of different regions of N.C. 100 under X-ray and ultra-violet excitation. Let i_0 be the intensity of the continuous spectrum given by X-rays and let i be the intensity of the fluorescent spectrum given by ultra-violet light. Then the intensity of fluorescence under X-rays is

$$\mathrm{I} = i_0 + ki \tag{1}$$

according to the above ideas. If we denote by subscripts 1, 2, 3 the three areas of the diamond showing different intensities of luminescence, then

$$\frac{\mathrm{I}_3}{\mathrm{I}_1} = \frac{i_0 + ki_3}{i_0 + ki_1} = \frac{\mathrm{K} + i_3}{\mathrm{K} + i_1}, \text{ putting } \frac{i_0}{k} = \mathrm{K} \tag{2}$$

In arbitrary units, we have $\mathrm{I}_3/\mathrm{I}_1 = 2 \cdot 5$ and $i_3 = 5 \cdot 0$, $i_1 = 1 \cdot 0$, so that K comes out to be $6 \cdot 33$. Substituting the values for i_1 and i_2 and K in

$$\frac{\mathrm{I}_2}{\mathrm{I}_1} = \frac{\mathrm{K} + i_2}{\mathrm{K} + i_1}, \qquad \frac{\mathrm{I}_2}{\mathrm{I}_1} = 1 \cdot 78 \tag{3}$$

which is in fairly good agreement with the experimentally determined value of 1·6 given in section 2. So also, this idea makes it intelligible why the maximum range of luminescence intensities is only 1 : 50 with X-rays while it is as large as 1 : 1000 with ultra-violet.

6. MECHANISM OF THE PRODUCTION OF LUMINESCENCE BY X-RAYS

In section 4, the results of experiments were described, which show how the intensity of luminescence varies with the intensity and hardness of the X-rays, the voltage applied to the X-ray tube and so on. A quantitative explanation of these results must be sought for in a theory of the mechanism of the production of the luminescence. It is obvious that the luminescence cannot be the direct outcome of the absorption of X-rays, for this results only in the ejection of photoelectrons which are of very high energy (of the order of tens of kilovolts) compared with energies of the order of a few volts associated with the luminescence. These photoelectrons are, however, rapidly absorbed in the medium as a result of the ionisation they produce. It is these low energy ions that are responsible for the production of luminescence.

Using these ideas, it is possible to deduce an expression for the intensity of luminescence. Let $u_\lambda \, d\lambda$ be the intensity of X-rays at the point concerned in the spectral region λ to $\lambda + d\lambda$ and let a_λ be the fraction of this absorbed per unit length in the medium. a_λ is obviously equal to $\rho\mu_\lambda$, where ρ is the density and μ_λ the mass absorption coefficient. Then the amount of X-rays absorbed per unit area in a thickness dt of the medium is clearly $a_\lambda i_\lambda d\lambda dt$, which is obviously proportional to the number of photoelectrons produced. This is not exactly true, since part of the X-rays absorbed is due to scattering and to the Compton effect. The assumption is, however, approximately true, particularly for the longer wavelengths. Now, the photoelectrons produced by the X-rays are absorbed within such a short distance (of the order of 0·01 mm.) that it is reasonable to assume that they are absorbed as soon as they are produced* with the formation of low-energy ions. However, the number of ions so produced should depend on the energy of the photoelectron. Since the production of each ion requires, on the average, a certain energy, we may suppose that the total number of ions produced is proportional to the energy of the photoelectron, *i.e.*, is inversely proportional to the wavelength of the X-ray, since the difference in energy between the X-ray and the photoelectron is only a few electron volts (the K absorption limit for carbon corresponds to an energy of 284eV), which is small ($< 2\%$) compared with energies of the order of thousands of electron volts for the X-ray. Consequently, if one takes the intensity of fluorescence I at any point to be proportional to the number of ions per unit volume generated at that point, then

$$I = K \int_{\lambda_m}^{\infty} \frac{a_\lambda u_\lambda}{\lambda} \, d\lambda, \text{ where K is some constant} \qquad (4)$$

We shall now apply this general formula to calculate the variation of the intensity of fluorescence with various factors and compare it with the experimental results described above. The integral in (4) was evaluated by numerical integration, by dividing the range of wavelengths into a large number of sections and substituting the values of a_λ, u_λ and λ for each. The spectral variation in the intensity of white X-rays given out by a tungsten target has been studied by a number of investigators, but the only set of results covering a wide range of voltages which was found useful for the calculations were those given by Ulrey (1918). Although these have not been corrected for the variations in the structure factor of the crystal, etc., they form a fair basis for the calculations, which are themselves expected to be not very accurate. Besides, no data as to the intensity of the characteristic radiation under the same conditions are available and so no account was taken of the characteristic radiation. The data for white radiation were corrected for absorption in the window of the X-ray tube, which set the upper limit for λ at 3 Å.U. The values of the absorption coefficients were taken from standard tables (*e.g.*, Compton and Allison, 1935) and were obtained by interpolation.

---

* This is easily proved. If the X-rays are absorbed with an absorption coefficient a and the photoelectrons with a coefficient b with the formation of a tertiary product (ions), then the concentration of this tertiary product at a distance x from the boundary of the medium can be shown to be practically proportional to the intensity of the primary X-rays for values of $x > (\log b/a) / (b - a)$. Actually, for diamond this comes out to be 0·01 to 0·02 mm. for the X-rays used in these studies.

(*a*) *Variation in the intensity of fluorescence with the distance from the front edge when the diamond is kept with its edge towards the X-ray tube.* It is easily seen that the intensity at a distance x cms. from the edge is

$$I_x \propto \int \frac{i_\lambda\, a_\lambda}{\lambda}\, exp\,(-a_\lambda\, x)\, d\lambda \qquad (5)$$

where $i_\lambda d\lambda$ is the intensity of white X-rays emerging from the X-ray tube in the range λ to $\lambda + d\lambda$. The theoretically calculated values are represented as the continuous curve in Fig. 2, while the circles are the experimetnal values obtained from the first microphotometric trace in Fig. 1. The agreement is seen to be remarkably good, except for the first point, which is much above the theoretical curve. This is obviously due to the presence of the characteristic L-radiation of tungsten in the region 1·0 to 1·5 Å, of which no account is taken in the theory. These are absorbed to a very large extent in the first 0·1 cm. and practically completely in 0·2 cm.

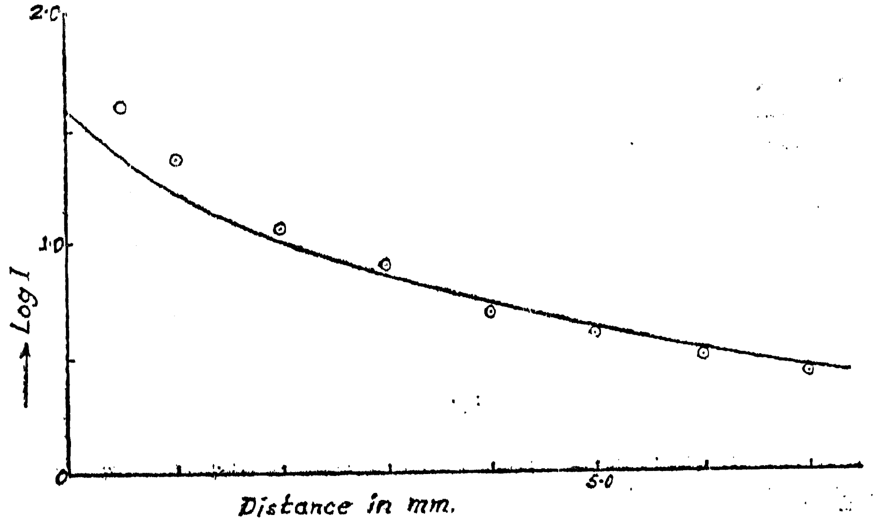


FIG. 2

(*b*) *Variation of the intensity with voltage.*—Under the experimental conditions, it is the total luminescence produced in the full thickness of the diamond that matters. Consequently, one must consider the total amount of X-rays of each wavelength that is absorbed in the diamond while calculating the luminescence intensity. Obviously this is proportional to $i_\lambda\,\{1 - exp\,(-a_\lambda l)\}$, where l is the length of the path traversed by the X-rays in the medium. If the diamond is kept at an angle θ to the X-ray beam, $l = t$ cosec θ where t is the thickness of the crystal plate. Hence,

$$I_V \propto \int_{\lambda_m}^{\infty} \frac{i_\lambda}{\lambda}\,\{1 - exp\,(-a_\lambda\, l)\}\, d\lambda \qquad (6)$$

Both the lower limit of integration and i_λ vary with the voltage. The results of the calculations for a number of voltages are represented as a continuous curve in Fig. 3, in which log I_V is plotted against log V. The experimental data are shown by crosses against the corresponding values of the R.M.S. voltage. The agreement with theory is satisfactory. For the lowest voltage, however, the experimental point is appreciably above the extrapolated theoretical curve. This can be explained to be due to the presence of characteristic radiation, the relative proportion of which is larger for smaller voltages, as in the present case.

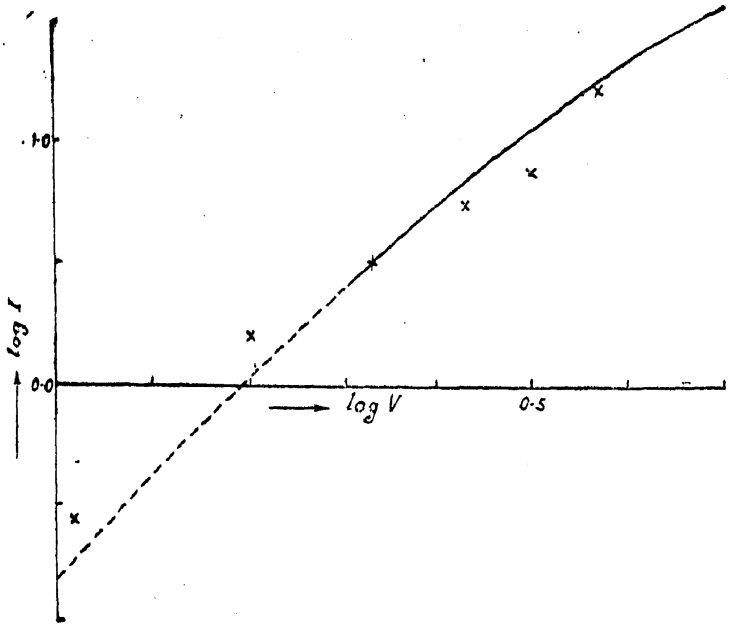


FIG. 3

(*c*) *Reduction in the luminescence intensity when aluminium foils are introduced.*—With an aluminium foil of thickness T introduced, the formula for the intensity is

$$I_T \propto \int_{\lambda_m}^{\infty} \frac{i_\lambda}{\lambda} \{1 - exp\,(-a_\lambda\, l)\}\, exp\,(-b_\lambda\, T)\, d\lambda \qquad (7)$$

where b_λ is the linear absorption coefficient for aluminium. The results of calculations made with formula (7) are shown in Fig. 4. The agreement with experiment is reasonably good in this case also.

These calculations thus support the idea that the production of luminescence by X-rays should be considered to be a tertiary phenomenon, namely, originating as a result of the ionisation produced by the photo-electrons ejected by the primary X-rays. Of course, the recoil electrons produced by the Compton scattering should also produce luminescence;

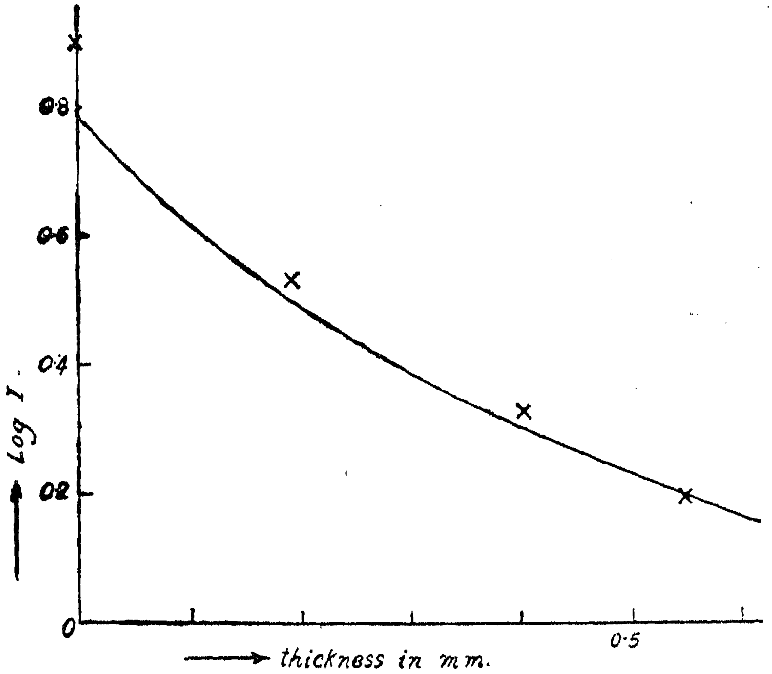


FIG. 4

but the contribution due to these is comparatively small for X-rays which are not very hard, as were used in these experiments.

My sincere thanks are due to Prof. Sir C. V. Raman for the suggestion of the problem and for the discussions I had with him during the course of the investigation.

SUMMARY

The paper deals with the investigations carried out by the author on various phenomena connected with the luminescence of diamond excited by X-rays. The fluorescence generated by X-rays was found to be much weaker and also to vary over a smaller range of intensities than that excited by ultra-violet light. The colour as well as the patterns of luminescence were the same as those excited by ultra-violet light, except that the patterns had less of contrast. By photographic photometry, the fluorescence intensity was found to be directly proportional to the current through the X-ray tube and to vary roughly as the cube of the voltage. Experiments are described which show that soft X-rays are more effective in producing luminescence than hard X-rays.

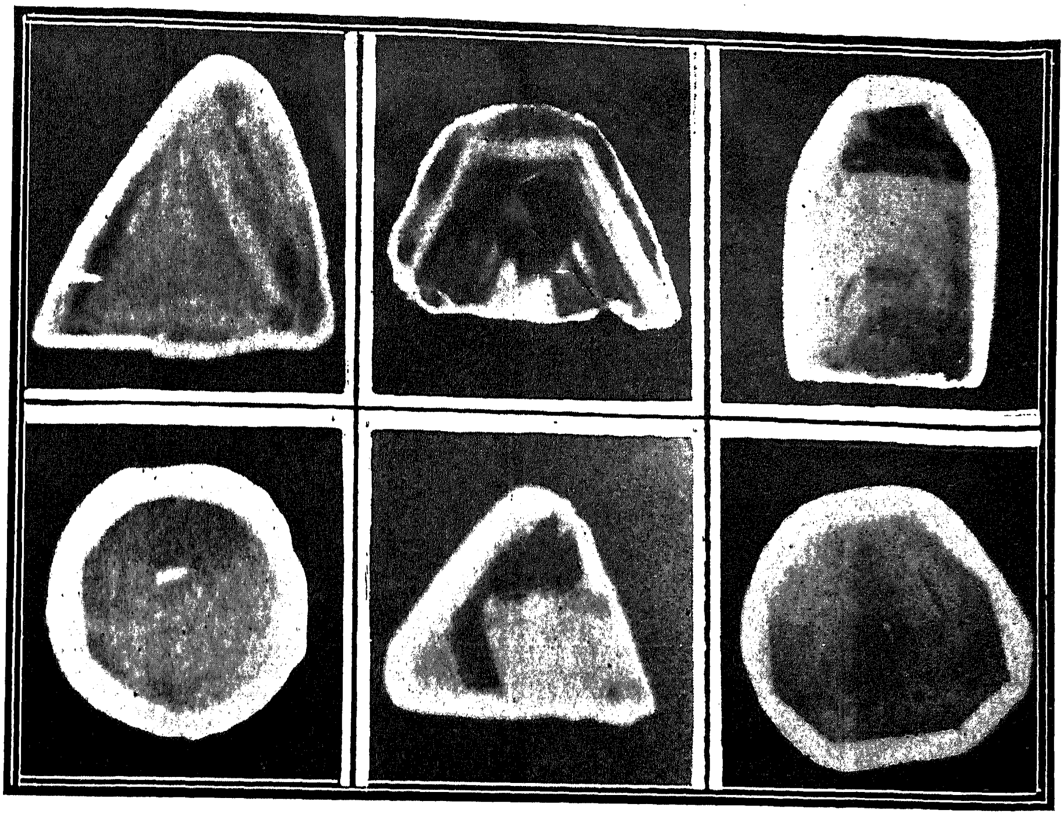
The luminescence spectrum of a brightly blue luminescent diamond excited by X-rays consisted of bands on the longer wavelength side of 4156 Å.U., these coinciding with those in the spectra excited by ultra-violet light, but there was a continuous spectrum on the shorter wavelength side, which was crossed by the absorption bands of diamond. The principal electronic line at 4156 Å.U. occurred as an absorption line. With a weakly blue-

fluorescent diamond, the spectrum was continuous, extending on either side of 4156 Å.U. with a trace of an absorption line at 4156 Å.U. A probable explanation for these is given, which also makes it intelligible why, with X-rays, the fluorescence intensity does not vary as much as with ultra-violet rays.

It is suggested that the luminescence arises as a result of the ions produced by the photoelectrons which are ejected by the X-rays. On this basis, quantitative formulæ are developed to explain the experimental data, and are found to hold fairly well.

REFERENCES

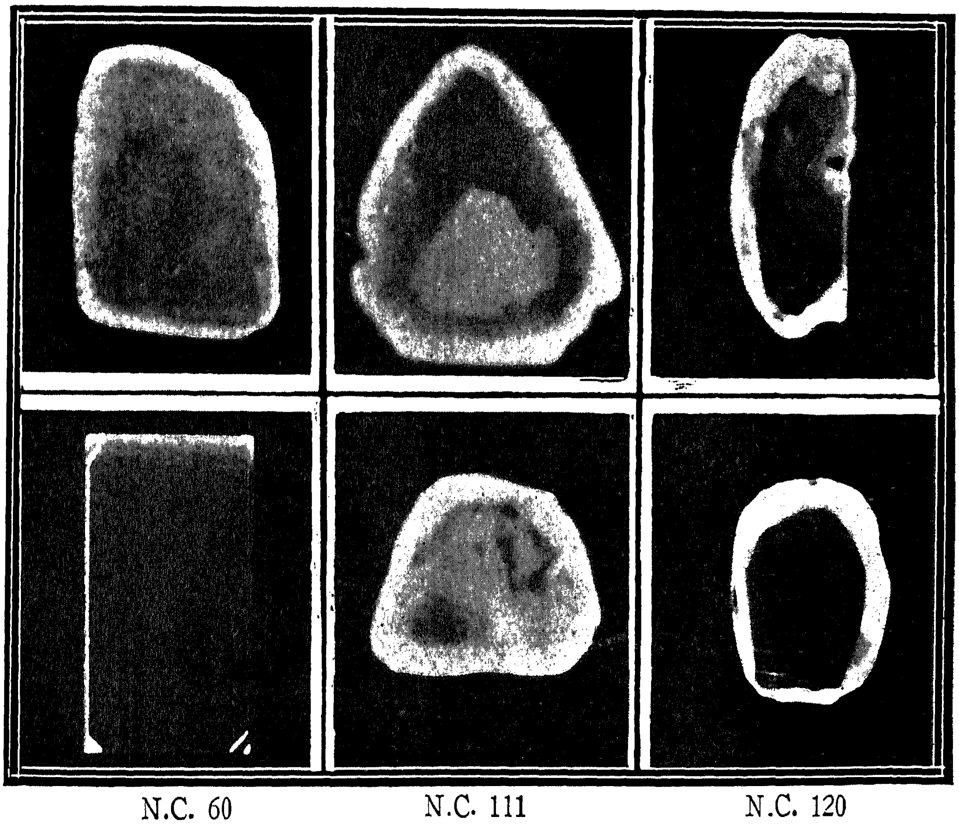
1. Compton and Allison .. *X-Rays in Theory and Experiment*, Macmillan, 1935, p. 799.
2. John .. *Ind. J. Phys.*, 1931, **6**, 305.
3. Mani, A. .. *Proc. Ind. Acad. Sci.*, 1944, **19A**, 231; **20**, 117, 323; 1945, **21**, 280.
4. Nayar, P. G. N. .. *Ibid.*, 1941, **13**, 284.
5. Ramachandran, G. N. .. *Ibid.*, 1946, **24**, 65.
6. Raman, Sir C. V. .. *Ibid.*, 1944, **19**, 199.
7. Rendall, G. R. .. *Ibid.*, 1946, **24**, 168.
8. Sunanda Bai, K. .. *Ibid.*, 1944, **19**, 274.
9. Ulrey, C. T. .. *Phys. Rev.*, 1918, **11**, 401.



N.C. 115 N.C. 118 N.C. 82

N.C. 80 N.C. 88 N.C. 99

Fig. 5. X-Ray Luminescence Patterns



N.C. 127 N.C. 100 N.C. 122

N.C. 60 N.C. 111 N.C. 120

Fig. 6. X-Ray Luminescence Patterns

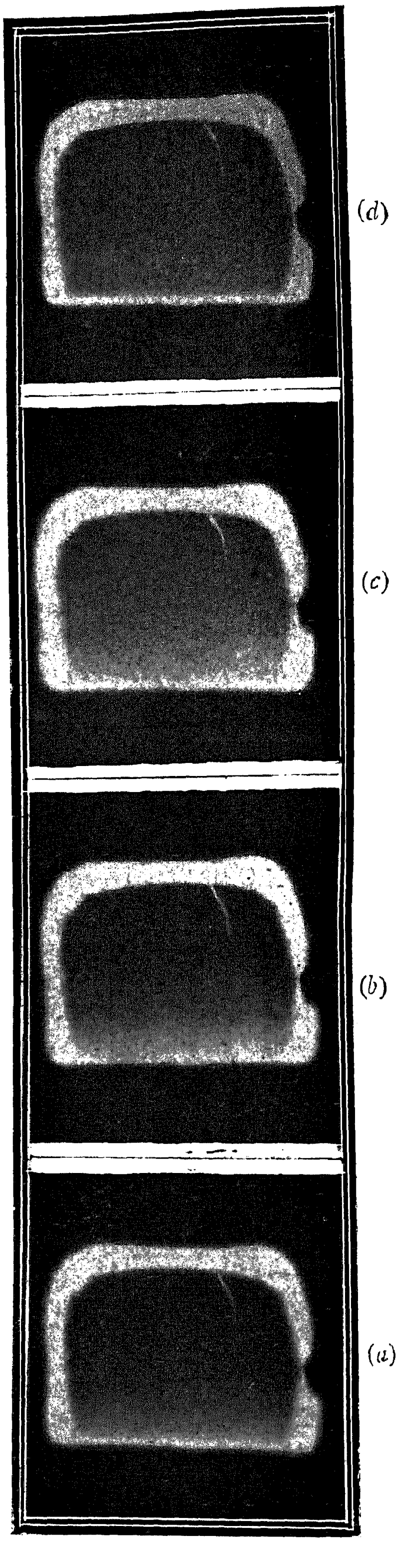


FIG. 7. For explanation see text

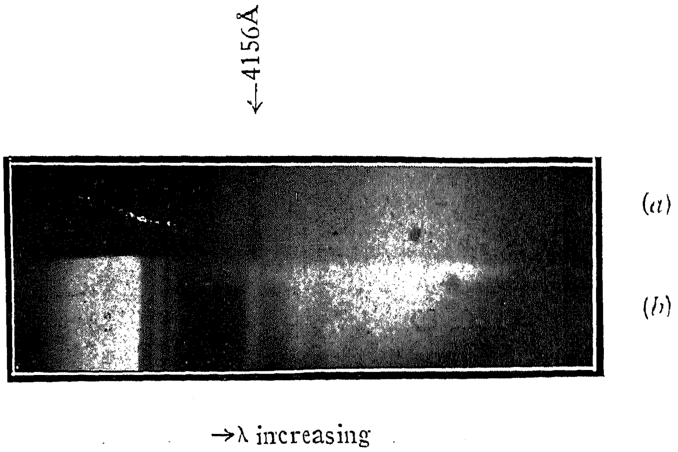


FIG. 8

Luminescence Spectrum of N.C. 73 with

(*a*) X-Ray excitation and

(*b*) Ultra-Violet excitation