

DIFFERENCES BETWEEN COUNTING AND
NON-COUNTING DIAMONDSPART I: COUNTING PROPERTIES AND SPECTRAL
TRANSMISSION

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Synopsis

In this paper the comparison is given of 36 diamond specimens, selected on their spectral transmission at 2536 Å. The comparison includes the efficiency and the maximum value of charge pulses in response to α -particles, and transparency to ultraviolet wavelengths below 3000 Å. The counting property is shown to be a property of the crystal itself, a conclusion which will be confirmed by experiments described in part II. The ultraviolet transparency is the same in practically all crystals.

1. *Introduction.* When investigating properties of diamond crystal counters one always comes up against the problem of selecting specimens which are useful as counters ¹⁾ upto and including 11). Of course one may buy or lend a few hundred diamonds, and select the counting ones in the straightest way possible. That is, after evaporating or painting electrodes to all crystals, to measure the effect due to α - or β -particles, or γ -quanta. The detection of such effects is made with the aid of a pulse-amplifier and oscilloscope or discriminator with scale. The procedure is described e.g. in a paper of the present authors ¹⁵⁾. However, this method is rather laborious and not very convenient. Apart from the trouble to obtain satisfactory electrodes, one has to eliminate surface conduction and spurious counts. It is of practical value to know whether other properties of the crystal are correlated with the counting property.

The same problem might be stated more principally. There was — notwithstanding many theoretical suggestions in this field — very little knowledge of what kind of correlation exists between the

counting property and other qualities of the crystals such as luminescence, photo-conductivity, impurity content, structure or internal surfaces. It is not even known if the photo-conductivity and the counting property are to be attributed to the ideal crystal or to impurities. R o b e r t s o n, who together with his coworkers found the correlation between the photo-conductivity and the ultraviolet transparency to be characteristic for a minor number of diamonds (labelled as diamond II)¹²⁾, suggested the photoconductivity to be due to imperfections of the crystal¹³⁾. The same suggestion was made by L o n s d a l e, in order to explain the relatively low number of counters among diamonds⁸⁾. An entirely other correlation between intense blue luminescence and counting was suggested by F r e r i c h s¹⁴⁾, an evidence which in our opinion, as will be discussed in part II, did not support his view.

The authors encountered the problem outlined right at the start of their investigation of diamond counters²⁵⁾. About twenty diamonds were lent, of which two specimens showed counting properties when irradiated with α -particles (of Polonium) or β -particles (of Ra D + E). In a paper by F r i e d m a n, B i r k s and G a u v i n⁵⁾ a correlation was stated analogous to the one found by R o b e r t s o n between the ultraviolet transparency and the counting of γ -rays.

For that reason the transparency of the diamonds at the time at our disposal was studied. This investigation was performed in a simple manner. The light of a quartz high pressure mercury lamp was passed through a quartz monochromator, set so as to allow passage of the 2536 Å line only. This light then passed through a quartz plate, behind which a green luminescent powder was put. If the light is interrupted by a diamond, there is a dark spot in the luminescence, when the diamond is ultraviolet opaque. The results appear to be in full accordance with those given by Friedman et al.; the two counting diamonds were ultraviolet transparent, and the others ultraviolet opaque. This was considered sufficient evidence to justify the application of this method of selecting more diamonds.

So in the course of time we obtained a collection of 36 diamonds, of which 3 were opaque to 2536 Å, one partly transparent and the other crystals transparent. Of these diamonds the counting of α -particles was studied in detail, together with the spectral transmission in the region of 2000–3000 Å. This part of the investigation

is described in the present paper. An extension to the comparison of the birefringence and luminescence is given in part II. From the results given in part I it appears that the selection of diamond counters on their spectral transmission in the ultraviolet is a fair but not so very excellent a method. One third of the collection are counters. In part II an improvement of the method is studied, resulting in the elimination of 20 transparent diamonds as non-counting, on account of their mosaic structure observed with the petrographic microscope. Of the remaining 16 diamonds 13 are counters.

2. *The counting efficiency and the magnitude of the maximum charge pulses.* The 36 diamonds investigated are labelled from 0 to 35. The numbers 6, 7, 8, are opaque to 2356 Å; no 25 is partially transparent, the numbers 0, 1, 2, 4, 9 up to and including 16, and 25 are counters. All the others do not count. The counting property was tested with the aid of α -particles. Moreover the efficiency and the maximum value of the charge pulses, given by the crystal, was determined, and this was done for both sides of the crystal. The efficiency was found by measuring, with the aid of an ionisation chamber, the number of particles, emitted by the Po-source.

The circumstances of the irradiation were mostly identical: the distance of the source to the crystal was 14 mm, a diaphragm of

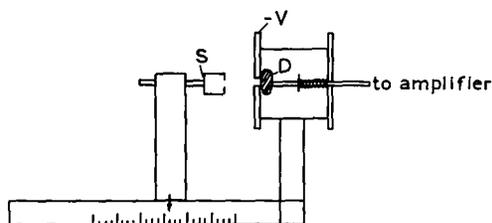


Fig. 1. The crystal holder and the source of α -particles.
D = diamond; S = source; V = voltage applied.

0,13 mm² was used at 4 mm of the source, and the surface of the diamond was 6 mm². This implied that only the central part of the diamond was irradiated. In order to prevent the ionisation of the air surrounding the crystal, the diamond holder screened the α -particles, which otherwise pass the sides of the diamond. The arrangement is sketched in fig. 1.

The diamonds showed a difference in counting rate and maximum signal at the two flat sides. At both sides the effects were measured, that is to say, the α -particles entered the crystal at the cathode; after measuring at one side, the other side was chosen as cathode and irradiated.

The results, as to the efficiency and the maximum value of the charge pulses measured, together with the thickness and the field-strength used, are given in the table I. Before judging the results

TABLE I

Diamond	Thickness	One side of the crystal		Other side of the crystal	
		Max. signal I	Efficiency	Max. signal II	Efficiency
0	1,24 mm	95%	68%	18%	53%
1	1,11	100	94	15	not measured
2	1,07	92	25	10	30
4	1,63	4	52	10	31
9	0,99	33	31	28	22
10	1,36	4	12	13	14
11	1,46	6	27	6	24
12	1,79	60	46	17	18
13	0,78	12	14	98	75
14	1,27	25	29	11	47
15	1,54	11	21	7	14
16	1,35	19	39	15	38
25	1,26	5	4	33	47

The field strength used is 4000 V/cm, the maximum signal of 100% corresponds with 8,6 eV/electron liberated. The efficiency is given in absolute value compared with the response of an ionisation chamber and with an accuracy of plm. 5%. The accuracy of the max.-signal depends on its value; it is approximately 1% of the maximum signal of diamond I.

one has to consider the limits imposed by the experiments. The efficiency is always the efficiency of a (central) part of the crystal; it is derived only from those pulses which excite the maximum noise signals (that is above 9.000 electron charges). For comparison, the maximum signal of the charge pulses we ever obtained in the same arrangement was about $4 \cdot 10^4$ e. If the energy necessary to liberate one electron is 8,6 eV, and the energy of the α -particles 4 MeV, the charge pulses of 10^4 e, which might be detected in a crystal of 1 mm thickness, corresponds to an average distance of 20μ covered by the electrons in the crystal. Most of the values given (on efficiency and maximum value of the pulses) were taken after an irradiation of the crystal by a comparative low quantity of 10^5 α -particles. In the more

intensively investigated crystals (number 0, 1, 2 and 13) the maximum signal and the counting rate increased after a certain time of use. So the values given are to be taken as approximate values; they might be ten or twenty percent less than the optimum value given by the crystal after a proper treatment.

The magnitude of the maximum pulses in one crystal is given in % of the optimum value obtained from diamond 1 at the same field strength. The fact that most diamonds yield only minor signals, might be explained by internal cracks and a variation, if any, in the number of traps/cm³ present. From these considerations it will be clear that a one to one correspondence between an optical and the counting property is not to be expected. This point of view is taken by the authors, as it seems hardly possible to obtain a three dimensional picture of the distribution of traps and internal surfaces in a diamond, by optical means. And yet those are the qualities by which the counting specimens have to be judged. The best thing one might hope for is to obtain a large correspondence, by an elimination of all those diamonds, such as ultraviolet opaque ones, which certainly do not count, and by selecting by another optical criterion from the ultraviolet transparent ones those diamonds, which have a large probability to act as counters.

3. *The ultraviolet transparency.* Because of the large differences in counting for various diamonds selected on account of total transmission, it was considered important to study the ultraviolet transparency more closely. The variation in the absorption of diamonds in the region between 2000 and 3000 Å was mentioned and measured already by several authors^{16) 12) 17) 5)}. Our interest, however, was not mainly in the ultimate wave length at which diamonds might still be transparent, but in the possible variations in the absorption of one specimen. This might be investigated by photographing the diamond, while light of a monochromator of several selected wave lengths e.g. 3600, 3000 or 2500 Å, passes through the crystal. The same result can be obtained by photographing the ultraviolet line spectrum of a mercury light source, using a spectrograph with a wide slit, in which the diamond is clamped. This method is used here. Those lines which are not overlapped by others give a sharp picture of the diamond at their wave lengths. Fig. 2 gives the arrangement of the spectrograph, fig. 3 the mounting of the crystal in the

slit. The sharpness of the picture is obtained with the aid of a diaphragm in the spectrograph. A point on a diamond of one mm thickness is diffused to a spot of 0,02 mm diameter in the picture. In this way fine deviations in the ultraviolet transparency can not be observed. For that reason the observation is restricted to deviations extending over a larger area. Improvement of the method would not have been justified because of the variations in the surfaces of a

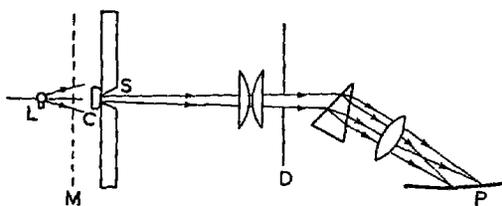


Fig. 2. The spectrograph.

L = lightsource; M = matted quartz plate; C = crystal; S = slit;
D = diaphragm; P = photographic plate.

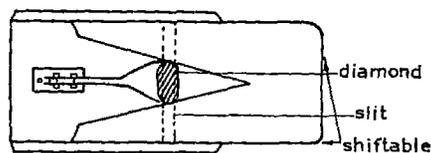


Fig. 3. The mounting of the diamond on the slit of the spectrograph.

number of diamonds which were not, or not sufficiently polished. These surface variations and the prismatic form of some diamonds are the reasons for setting a matted quartz plate between the light source and the diamond, and for using the diaphragm to sharpen the picture.

Intense and sharp pictures are obtained for the 3342, 2967, and 2536 Å lines; less intense but still sharp for the 3022, 2894, 2753 and 2700 Å lines. Unsharp are those for the lines at 3655, 3130, 2655 Å, on which less intense lines are superimposed. Some of the spectra are given in fig. 4. From these pictures the conclusion is that absorption starts all over the surface at 2240 Å for ultraviolet transparent crystals. Of the three diamonds classed as ultraviolet opaque, the absorption starts at 2850 Å for no 8, diamond 6 shows an absorption in a part of the crystal beginning at 3200 Å, diamond 7 is transparent up till 2770 Å. The fourth deviating diamond is no. 25, a counter,

whose opacity increases with wave length in the central part in the crystal, but which remains transparent at the edges. The counting property of this diamond was tested with electrodes covering nearly the whole of the crystal. All other diamonds are transparent up till 2240 Å.

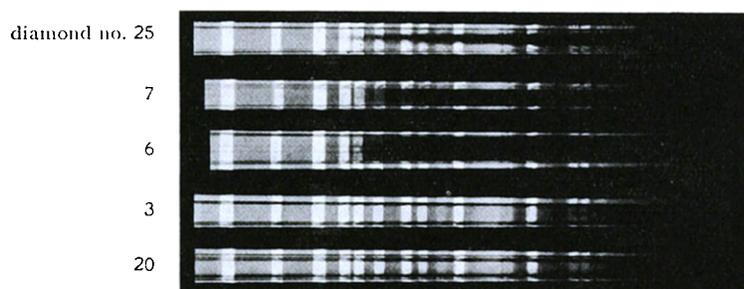


Fig. 4. Some pictures of the ultraviolet transparency.

We may state that indeed the long list of non-counting diamonds, from no. 17 up till and including 35, all belong to the ultraviolet transparent class.

4. *Conclusion.* The spectral transmission yields only a minority of crystals which count α -particles. The same applies to β -particles as was confirmed by comparing the response from a Ra D + E source. The minority is about $1/3$ of the specimens investigated. To improve this selection one has to consider another means. For this purpose the luminescence and the birefringence were chosen, as will be described in part II. However, one might consider the counting property to be a property of the crystal itself, notwithstanding the large variation of the specimens. This is proved by the high efficiency of the diamonds 0, 1 and 13. It seems impossible that such efficiencies are obtained from counting along cracks. The ultraviolet transparency does not give an indication as to the reason of the large variations observed in efficiency and maximum signals.

Received 10-10-51.

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Received 10-10-51.