The crystal counter

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Introduction.

As is well known it is possible to detect α-rays with the help of an ionisation chamber backed by a linear amplifier and an oscillograph. Each α-particle gives rise to slight ionisation in the gas of the chamber. The electrodes of the instrument between which a high voltage is applied, are charged with 10^5 elementary charges, when an α-particle of 4 MeV enters the chamber. The corresponding voltage-pulse is amplified and detected on the screen of an oscillograph. The pulse-size on the screen is proportional to the charge-pulse on the electrode of the ionisation chamber and the ratio between signal and noise is optimal when the electrical behaviour of the amplifier and oscillograph is equivalent to an ideal differential circuit backed by a ballistical oscillograph of an indication time of 0,03 à 0,001 sec.[1]).

The ordinary combination of gasfilled ionisation chamber and linear amplifier is not sensitive for β- and γ-rays because their differential ionisation is too small. The range of a α-particle of 4 MeV f. i. is 2,5 cm in air of 1 atm, so that by using an ionisation chamber with a cross-section of a few cm, we can catch the total range within the chamber. The range of a β-particle of the same energy is however many meters. This means that an adequate ionisation-chamber would require impractically large dimensions and capacity.

Increasing the pressure of the gas or using a liquid generally gives difficulties, caused by the small mobility and the high rate of recombination of the ion pairs produced. There is one interesting exception: the solid and liquid argon-counter developed in England by Davidson and Larsh and by Hutchinson[2]).

In 1942 Mr. van Heerden proposed in our laboratory the use of a crystal instead of a gas in the ionisation-chamber. The electrons of the ion pairs formed in the crystal under the influence of α-, β- of γ-particles would move through the conductionband of the

crystal and a charge would be induced on the electrode of the ionisation chamber exactly as in the case of a gas filled chamber. Indeed he succeeded in detecting α-, β- and γ-particles using an ionisation chamber consisting of a small parallel plate condenser with an AgCl crystal as dielectricum[3]).

The so-called crystal counter was cooled to the temperature of liquid air in order to eliminate the electrolytic conductivity in the AgCl.

During the congress we demonstrated a crystal counter working with a crystal of diamond, which was bombarded with α-particles.

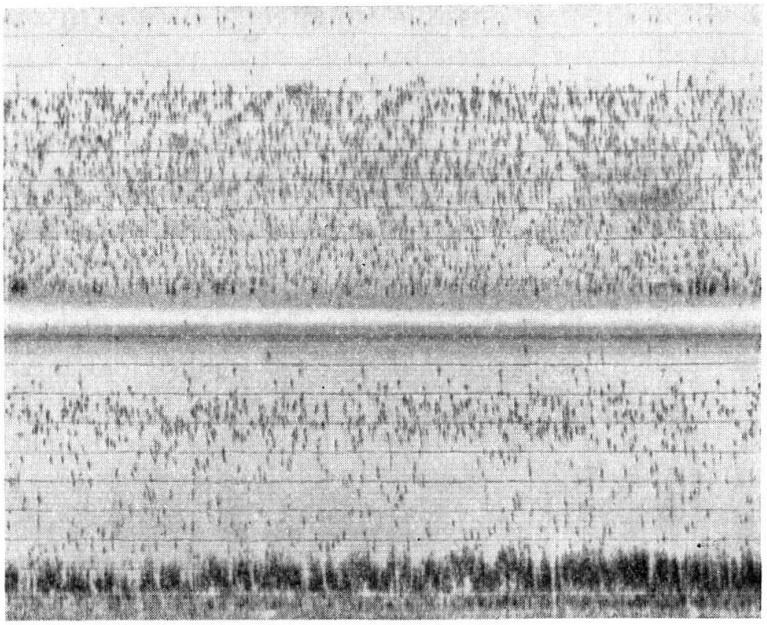

Fig. 1.

In Fig. 1 a record is reproduced obtained with the crystal counter of VAN HEERDEN. The lower part shows a number of practically equal pulses produced by mono-energetic β-particles which appear indeed to be of about the same sizes. The upper part shows a number of pulses produced by α-particles. In this case an AgCl-plate of a cross section of 1,5 cm and a thickness of 1,7 mm was used.

One of the great advantages of the crystal counter is the possibility of measuring the energy of a α-, β- or γ-ray. This is possible because under certain circumstances the number of ion pairs produced is proportional to the energy of the particle. Other advantages of the crystal counter are: high counting efficiency (~ 1) owing to the higher density and better conversion of energy into ion-pairs than in a gas and a short resolving time ($< 10^{-7}$ sec.).

Certain disadvantages may appear, when strains are present in the crystal, when polarisation effects occur or when a low temperature is necessary for the good performance of the crystal.

Determination of the energy of a α- or β-particle.

One of the advantages of the counter mentioned is the possibility of measuring the energy of a particle detected. In order to investigate this possibility in the case of β-rays VAN HEERDEN and one of the authors performed an experiment in which a mono-energetic beam of β-particles was projected on an AgCl-crystal[5]). To this purpose a RaE preparation and the crystal counter were placed in a magnetic β-ray spectrograph. The AgCl-crystal used was grown, selected and tempered with great care in order to obtain a single crystal without strain.

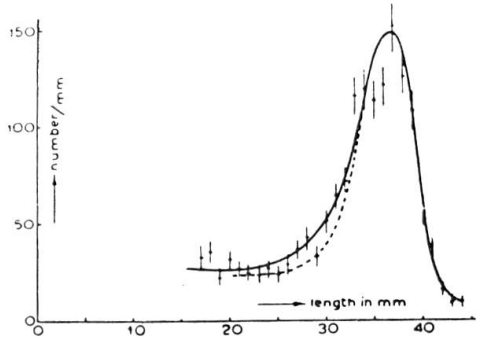

Fig. 2.

The distribution curve of the deflections caused by homogeneous β-rays. $H\varrho = 2500$; $E = 0.4$ MeV. $V = 200$ volt; 1 mm = 1200 e. c. Dotted: curve expected theoretically.

The distribution curve of the pulse-sizes obtained when the crystal was bombarded with mono-energetic electrons of 3.4 MeV is shown in Fig. 2. Most pulses have a size of 35 mm. There is, however, a spread in this size, which could be expected. The main causes are the noise of the amplifier and the reflection of the β-particles by the crystal. These effects being known, one can predict the result that would have been obtained with an ideal crystal and an ideal amplifier. It is shown by the dotted curve in Fig. 2. The conclusion is that the AgCl-crystal used behaves like an ideal crystal within the measuring-errors: β-particles of the same energy produce the same charge-pulses in the crystal, so that a crystal counter can be used for the measurement of the energy of β-particles.

Fig. 3 gives the relation between the size of the charge-pulses and the energy of the β-particles. For energies between 0 and 1.0 MeV

the relation is linear. The crystal counter completely fulfills the requirements. The mean energy necessary to produce one pair of ions is remarkably low: 7.6 eV (in nitrogen gas of 1 atm. 36 eV).

Fig. 4 gives the distribution of pulse-sizes obtained with the same AgCl-crystal when it is bombarded with mono-energetic α-particles of Polonium. Contrary to the expectation the size of the pulses is

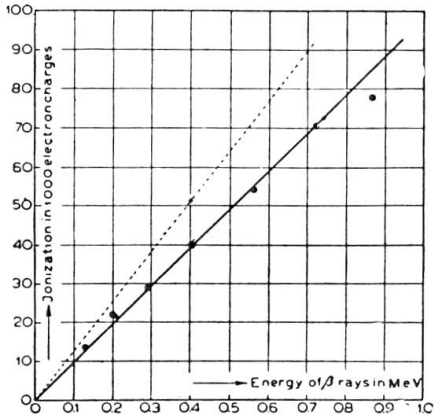

Fig. 3

The relation between the ionization and the energy of β-rays.
Dotted: the extrapolated saturation curve.

not the same. Also the mean energy for the production of an ion-pair is much higher (5.6 times) than in the case of β-particles. These two discrepances can be explained by assuming the existence

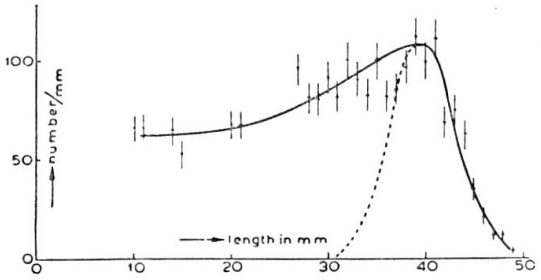

Fig. 4.

Distribution curve of α-ray reflections of Polonium.
1 mm = 2100e.c.
Dotted: curve expected theoretically.

of a surface-layer of bad quality. In this connection the recent experiments of YAMAKAWA[6]) on α-particles produced *within the body* of a mixed crystal by slow neutron capture (LiBr-AgBr) are of interest. They indicate that under these circumstances the energy per ion-pair appears indeed to be not substantially different from the value obtained for β-particles.

Elimination of polarization phenomena.

A rather troublesome disadvantage of the crystal counter is its polarization. This polarization becomes detectable as an appreciable decrease of the pulse size and the number of pulses, when the crystal is irradiated for a long time.

The explanation is slow accumulation of trapped charges, which give an electric field opposite in sign to the applied one. For diamond f. e. irradiated by α-particles an appreciable decrease occurs after about 10^7 α-particles have been counted.

We have carried*) out experiments on the way in which this polarization effect can be avoided. Various methods are in use.

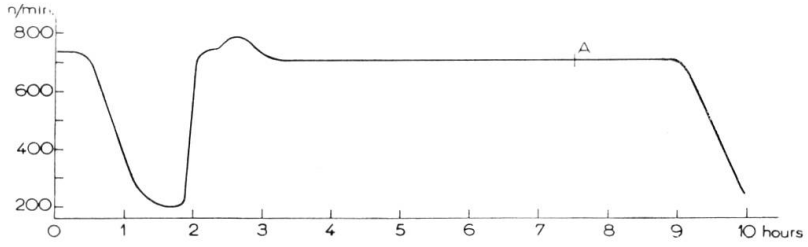

Fig. 5.

Counts per min. as a function of the duration of irradiation with α-particles. During the first two hours no red light is used. At that time the irradiation with red light begins and the counts per min. is rising to the original level. At A the red light is turned of.

In the first place one can periodically reverse the applied field, each time the same number of pulses have been counted. This method can only be applied however, when the charges captured are evenly distributed throughout the crystal, which is the case for high energy particles, for instance when measuring the output of a pulsed accelerator.

When measuring low energy particles, this method can not be applied, as in this case the trapped charges are not evenly distributed. This is due to the fact that the depth of penetration of the particles is only a fraction of the crystal thickness.

According to a second method the crystals are heated after a certain amount of irradiation. A disadvantage of this method is the decrease of the sensitivity during the irradiation.

We applied a third method by irradiating the crystal, in this case a diamond, with infrared and red light, during the counting. It turned out that the intensity of the red light can be increased to such an extent, that no charge is trapped at all, the trapped charges

*) These experiments were carried out by FREEMAN and VAN DER VELDEN.

being immediately removed by the red light. Fig. 5 shows the influence of the red light.

This methods can be applied to all sorts of particles, because there is no restriction regarding the place where the charge is trapped.

For diamonds at least the minimum wave length of the red light can be chosen in such in way, that there is no photoconductivity. After such an irradiation with red light, the crystal behaves like an entirely new one and polarisation becomes appreciable again after an impingement of about to 10^7 α-particles per mm^2.

It is clear that one of the serious disadvantages of the crystal counter can be overcome, so that the applicability of the crystal counter is increased.

Bibliography.

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[2]) Davidson and Larsh, Ph. Rev. **74**, 200 (1948); Hutchinson, Nature **162**, 610 (1948).

[3]) Van Heerden, Thesis Utrecht, 1945; Van Heerden, Physica, in preparation.

[4]) Compare also the work of Kosmata, Huber and Jentschke: Stetter, Verh. deutsch. Phys. Ges. **22**, 13 (1941).

[5]) Van Heerden and Milatz, Physica, in preparation.

[6]) Yamakawa, Thesis, Princeton 1949; Hofstadter, Nucleonics, April and May 1949.