# Scintillation Counters

**O. R. Frisch,** Cavendish Laboratory, Cambridge, England.

Zinc sulphide and diamond produce scintillations (light flashes) on bombardment with α-rays; that property was discovered early in this century and for about two decades it remained the only means of detecting individual α-particles. Much of the classical work in radioactivity and nuclear physics was done with its help. Scintillations were counted in those scattering experiments (by GEIGER and MARSDEN) which led to RUTHERFORD's nuclear atom; in RUTHERFORD's discovery that nitrogen nuclei could be disintegrated (transformed) by impact of an alpha particle, and in all the early work on nuclear transformation which followed. It was even used (1932) in COCKCROFT and WALTON's first successful disintegration of lithium nuclei by artificially accelerated protons.

Yet the method had severe short-comings. It was laborious, unreliable, and slow; not much more than twenty scintillations per minute could be counted, or the observer was likely to miss a good many. Conversely at low counting rates the observer was likely to "see" scintillations which were not there.

When electronic valve amplifiers were developed which could detect the small ionisation currents due to single alpha-particles and protons the scintillation method went out of use. Now, after about 20 years, it has come back, owing to the development of a new electronic tool, the photo-multiplier.

An electron multiplier contains, in a high vacuum, a number of "dynodes", suitably shaped electrodes made from a material with high secondary electron emission. An electron falling on one of the dynodes will liberate, say, three secondary electrons which, owing to the shape of the dynodes, will be attracted to the next dynode where each of them will again produce three secondary electrons, and so on. In this way, with ten dynodes, a single electron falling on the first dynode will cause about $10^5$ electrons to be ejected from the last dynode, representing a current pulse which can be easily recorded by a moderately sensitive amplifier.

In a photo-multiplier a photo-sensitive cathode (usually a cesium layer on a suitable substratum of Ag or Ag—Sb) is so arranged that the electrons emitted from it are directed towards the first dynode

of an electro-multiplier. Cathodes can be arranged to emit electrons on the same side from which the light falls on them, or on the other side. The latter type is very convenient, because the light source can be placed very close to the photo-cathode, on the outside of the glass envelope, while the first dynode can also be close to the cathode, on the other side. Both these features make for compactness and high efficiency.

Even in the complete absence of light, electrons are emitted from the cathode because of its low work function; this thermal current is the greater in general the more sensitive the cathode. It causes background pulses to appear at the output of the multiplier, which under unfavourable conditions can be numerous enough to completely obscure the scintillation pulses.

To reduce the importance of that thermal background, several methods are available. In the first place, one can cool the multiplier. Cooling with solid carbon dioxide is usually sufficient to reduce the background pulses to a negligible amount. Secondly, if the background is not too large, one can employ two photo-multipliers in coincidence, both looking at the same piece of phosphor; it is very unlikely that two thermal pulses should happen to occur simultaneously and thus simulate a scintillation.

Both these methods entail additional trouble and expense. The best way is to use a good phosphor which produces large scintillation pulses each of which ejects many electrons from the photo-cathode and thereby produces a pulse much larger than the pulses due to thermal emission.

Of phosphors there is now a considerable variety. In addition to zinc sulphide a number of new inorganic scintillating phosphors have been found, such as zinc oxide, fluorite ($CaF_2$), thallium-activated sodium (or potassium) iodide, Scheelite ($CaWO_4$) and others. In addition, organic crystals containing co-ordinated double bonds have been found suitable, such as solid benzene, naphtalene, anthracene, stilbene, and suitable mixtures thereof; naphtalene containing 0.1% of anthracene is getting very popular. The effect of such small admixtures indicates the need for high purity.

The behaviour of inorganic and organic phosphors differs in several respects. In the first place, it has been stated that alpha particles give bigger pulses in inorganic phosphors than electrons of the same energy, while in organic phosphors the relation is reverse. However, recent measurements have thrown doubt upon this observation.

An important difference exists in the time behaviour, and this is connected with the different mechanism of luminescence. In the

inorganic phosphors a fast particle which passes through the crystal throws electrons out of their positions into the lattice, creating a number of vacancies at the same time; light is emitted when the electrons return to the vacancies. However, as the number of the electrons diminishes so does the number of vacancies, and the remaining electrons find it increasingly difficult to find a vacancy into which to drop. As a result the light emission does not fall off exponentially, but with a gradually increasing time constant, roughly as $1/t$. Empirically, the time constants found for various inorganic phosphors are usually greater than a microsecond.

In an organic phosphor the particle which passes through it excites individual molecules on its way, and the light emission is due simply to the de-excitation of those molecules. Hence the emission decays exponentially, and usually with a very short time constant. Decay times down to .02 microsecond have been reported, and it is not clear whether that lower limit is not imposed by the present measuring instruments.

The fact that organic phosphors give such very brief scintillations makes it possible to use them in connection with coincidence circuits of high resolution. In measurements of that kind, it is also a great advantage that scintillation counters have a very high sensitivity for gamma rays. That is due simply to the fact that fairly large blocks of phosphor can be prepared in a sufficiently transparent or translucent form to allow most of the light to escape, while absorbing a substantial fraction of the gamma quanta.

The high sensitivity for gamma rays and the short time constant of scintillation counters make them particularly suitable for the study of correlations between two gamma quanta emitted from a nucleus (or one gamma quantum and one other particle). Let us consider a specimen in which $N$ nuclei decay per second, each decay giving rise to the practically simultaneous emission of two gamma quanta. Two counters may be placed near that source in such a way that their efficiencies are $\varepsilon_1$ and $\varepsilon_2$ respectively (the efficiency here is defined as the probability that any given quantum should be recorded by that counter; it therefore includes the solid angle subtended by the counter). The counting rates recorded by the two counters separately will then be

$$A = N\varepsilon_1, \quad B = N\varepsilon_2$$

while the number of genuine coincidences is $C = N\varepsilon_1\,\varepsilon_2$ (neglecting angular correlation between the two quanta). In addition we have always a certain rate of accidental coincidences when the two coun-

ters are independently triggered within the resolving time $\tau$. The number of these accidental coincidences is $D = 2\,\tau\,N^2\varepsilon_1\varepsilon_2$ and should obviously be kept below the number of genuine coincidences so that it can be easily allowed for. This imposes the condition $2\,\tau\,N < 1$ on the strength of the source, and the rate at which true coincidences can be recorded is thus limited to about $C_{\mathrm{max}} \approx \varepsilon_1\varepsilon_2/2\,\tau$.

Scintillation counters have approximately ten times shorter $\tau$, and more than ten times higher gamma sensitivity than GEIGER counters. Hence their use allows one to record gamma coincidences at about a thousand times the rate possible with GEIGER counters. The recent great advance in our knowledge of angular correlation between successive gamma quanta would have been impossible with GEIGER counters.

The high gamma sensitivity of scintillation counters is also an advantage in the measurement of very weak gamma activities; this may have important applications in biology (use of gamma-active tracers). In that connection it should be welcome that the life of a scintillation phosphor and a photo-multiplier is probably nearly unlimited.

Scintillation counters for counting alpha particles and protons do not offer such fundamental advantages. But the arrangement is simpler, more robust, and more long-lived than the traditional ionisation chamber or proportional counter with its attending amplifier. The phosphor must be covered with a very thin metal foil which must be light-tight but need not be air-tight and is not liable to burst when the counter is introduced into a vacuum.

The light from a phosphor can be conveyed to the photo-cell either by lenses or mirrors, or more simply by internal total reflection in a rod of glass or transparent plastic. In this way the phosphor can be inserted into confined places or strong magnetic fields, while the photo-multiplier can be in a more convenient position.

Information on the energies of the particles entering the phosphor can be obtained from studying the intensity of the light flashes. In the case of monokinetic alpha particles falling on single crystals of suitable sulphides, the light flashes were found to be all equal to within a few percent. In the analysis of gamma rays by large crystals of organic phosphors the loss of light in the crystal may be substantial and may vary from point to point; it is not yet known to what extent this source of error can be reduced.

Ultimately the accuracy of energy measurements will be limited by purely statistical factors. The number of light quanta produced

by a particle of given energy is similar to the number of ions produced by the same particle in an ionisation chamber. However, only a fraction of these light quanta can be made to strike the photocathode, and of them only a fraction will eject a photo-electron. Hence the relative statistical fluctuation of pulse size is bound to be larger than in an ionisation chamber. The fluctuations will be raised by a further small factor (probably about 2 or less) owing to the statistical features of the electron multiplication process. However, the resulting accuracy may still be good enough to be very valuable in certain nuclear physics experiments.

Current research on the improvement of the method is concerned partly with the development of better multipliers. Unfortunately, the demands for highly efficient photo-cathodes and low thermal emission are somewhat contradictory; yet it might be possible to develop a photo-cathode which is very sensitive in the blue or near ultra-violet, while having sufficiently high work function to make thermal emission negligible. To achieve high resolution in coincidence work the multipliers should have enough stages to produce an output pulse big enough to be fed to a coincidence circuit without further amplification.

More immediate progress is to be expected from the improvement of phosphors both in the direction of brighter pulses and shorter time constants. The development of uniform and transparent crystals will be important for the measurement of particle energies.

*References*

W. H. JORDAN and P. R. BELL. Nucleonics 5, No. 4, 30 (1949) and references therein.

G. COWPER, "Scintillation Counting", Lecture given at Chalk River, June 1949. NRCC LE–22.

Conference on Scintillation and Crystal Counters, Univ. of Rochester, July 22–23, 1948.

Conference on Scintillation Counters, Oak Ridge, June 3–4, 1949.

G. T. REYNOLDS and F. B. HARRISON, Phys. Rev. **76**, 169 (1949).

P. R. BELL and J. M. CASSIDY, Phys. Rev. **76**, p. 183.

W. S. KOSKI and C. O. THOMAS, Phys. Rev. **76**, p. 308.

E. C. FARMER, H. B. MOORE and C. GOODMAN, Phys. Rev. **76**, p. 454.

J. PINE and R. SHERR, Phys. Rev. **76**, p. 455.

P. R. BELL, B. H. KETELLE and J. M. CASSIDY, Phys. Rev. **76**, p. 574.

L. B. ROBINSON and J. R. ARNOLD, Rev. Sci. Inst. **20**, 549 (1949).

J. D. GRAVES and J. P. DYSON, Rev. Sci. Inst. **20**, 560 (1949).

M. A. GRACE, R. A. ALLEN and H. HALBAN, Nature **164**, 538 (1949).

E. J. BOWEN and P. D. LAWLEY, Nature **164**, 572 (1949).

O. HUBER, F. HUMBEL, H. SCHNEIDER and R. STEFFEN, Helv. Phys. Acta **22**, 418.

K. P. MEYER, E. BALDINGER, B. HAHN and P. HUBER, Helv. Phys. Acta **22**, 420.

A. LALLEMAND, Journ. de Physique **10**, 235 (1949).