

Even in the time range where Geiger counters can be used the scintillation counters present the advantage of a higher efficiency for gamma-rays, and may permit the detection of slightly converted short-lived isomers which are difficult to observe with other techniques. Furthermore, one should not overlook the possibility of measuring much shorter times.

\* This document is based on work performed under Contract No. W-35-058 eng-71 for the Atomic Energy Project at Oak Ridge National Laboratory.

<sup>1</sup> H. Kallmann, *Natur und Technik* (July 1947).

<sup>2</sup> S. DeBenedetti and F. K. McGowan, *Phys. Rev.* **70**, 569 (1946).

<sup>3</sup> See preceding letter.

### Rotational Spectrum of OC<sup>14</sup>S, and the Nuclear Spin of C<sup>14</sup>

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THE pure rotational transition  $J=1 \rightarrow 2$  of carbon oxysulphide, OCS, made with C<sup>14</sup>, has been observed at 24, 173.0 ± 1 mc, which agrees with the value predicted from the frequencies observed for isotopic molecules.<sup>1</sup> No hyperfine structure as great as 0.5 mc is observable. In addition, the Stark effect pattern is visually identical with that of the C<sup>12</sup> isotopic molecule, showing no sign of hyperfine structure. Furthermore, the  $l$ -type doublet due to molecules excited to the first vibrational bending mode ( $v_2=1$ ) has been observed; these lines also show no hyperfine structure. With Townes<sup>2</sup> estimate of  $\partial^2 V / \partial z^2$  in this molecule, this means that the quadrupole moment of the C<sup>14</sup> nucleus is probably less than  $10^{-27}$  cm<sup>2</sup>. One can therefore conclude that the spin of C<sup>14</sup> is most probably zero, in accord with the findings of Jenkins<sup>3</sup> from band spectra (published after these measurements were made) and the as yet unbroken rule that even-even nuclei have zero spin.

Well-known and serious difficulties are encountered by current beta-ray theory<sup>4</sup> in attempting to explain the homologous  $4n+2$  series of beta-ray transitions He<sup>6</sup> → Li<sup>6</sup>, C<sup>10</sup> → B<sup>10</sup>, Be<sup>10</sup> → B<sup>10</sup>, and C<sup>14</sup> → N<sup>14</sup>. Of these the first two are apparently allowed, the last two highly forbidden, although all are expected to follow the same selection rules  $I=0 \rightarrow 1$  (no), and are in addition favored transitions by Wigner rules. It is perhaps worth pointing out that the polar vector interaction, obeying Fermi selection rules, makes the C<sup>14</sup> → N<sup>14</sup> transition second forbidden, as the  $ft$  value seems to require. In this case only the matrix element  $\int \alpha \times r$  survives, giving a definite predicted shape to the beta-spectrum which differs, albeit slightly, from the allowed shape. Thus, a sufficiently precise experimental determination of the beta-ray spectrum of C<sup>14</sup> may serve to show either (a) that the polar-vector interaction can explain the C<sup>14</sup> disintegration, in which case spin determinations in the other members of the series will assume even greater interest, or (b) that, as seems more likely, no single interaction can explain the series, and a new theoretical approach is necessary.

The  $l$ -type doublet of O<sup>16</sup>C<sup>14</sup>S<sup>32</sup> has the spacing 26.8 ± 0.4 mc, as compared with 24.9 ± 0.4 mc for O<sup>16</sup>C<sup>12</sup>S<sup>32</sup>. The parameter  $\alpha_2$  of the bending vibration is  $-9.4 \pm 0.3$  mc as compared with  $-10.6 \pm 0.3$  mc for O<sup>16</sup>C<sup>12</sup>S<sup>32</sup> (assuming symmetrical doubling of the rotational levels). The frequency of the C<sup>14</sup> line was not determined with sufficient precision to check the accepted nuclear mass of C<sup>14</sup>; because of the central position of the carbon atom, OCS is an unsuitable molecule for this purpose. The OC<sup>14</sup>S was prepared by G. Matlack and John F. Haskin of the Department of Chemistry and Chemical Engineering under the direction of Professor G. Glockler, from high specific activity<sup>5</sup> C<sup>14</sup> obtained from the Isotopes Branch of the Atomic Energy Commission.

<sup>1</sup> T. W. Dakin, W. E. Good, and D. K. Coles, *Phys. Rev.* **71**, 640 (1947).

<sup>2</sup> C. H. Townes, A. N. Holden, and F. R. Merritt, *Phys. Rev.* **72**, 513 (1947).

<sup>3</sup> F. A. Jenkins, *Phys. Rev.* **73**, 639 (1948).

<sup>4</sup> E. J. Konopinski, *Rev. Mod. Phys.* **15**, 209 (1943); J. R. Oppenheimer, *Phys. Rev.* **59**, 908 (1941).

<sup>5</sup> L. D. Norris and A. H. Snell, *Phys. Rev.* **73**, 254 (1948).

### The Use of Anthracene as a Scintillation Counter\*

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THE method of counting ionizing radiations by photoelectric measurement of the fluorescent light pulses emitted by certain organic substances was first

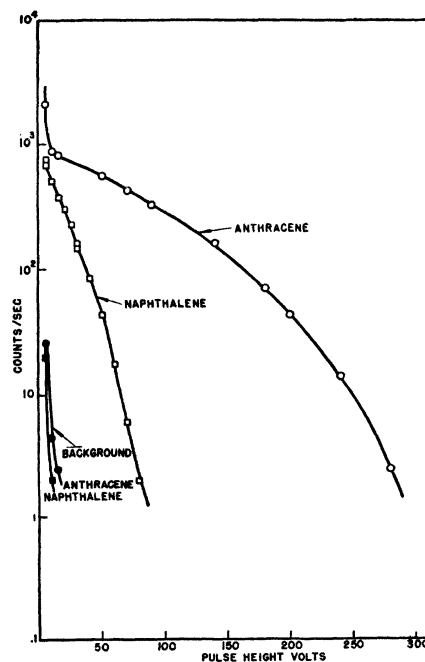


FIG. 1. CO<sup>60</sup> gamma-rays.

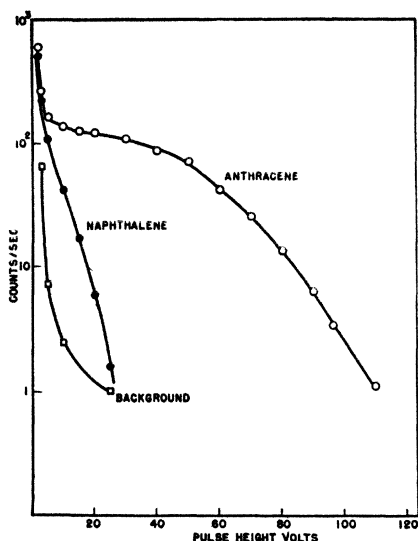


FIG. 2. Alpha-particles of Po.

pointed out by H. Kallman<sup>1</sup> and verified by M. Deutsch.<sup>2</sup> The substance most used by these authors is naphthalene, but both authors have suggested anthracene as a possible alternative.

In this laboratory we have prepared some transparent crystalline slabs of both materials, and their behavior as scintillation counters has been compared. It was found that it was more difficult to prepare satisfactory anthracene samples, but that these performed much better than naphthalene. Both kinds of samples were prepared by slow cooling of the melted materials. Anthracene had to be previously purified by sublimation and crystallization from hot benzene, and had to be melted in an atmosphere of nitrogen or argon. In this way clear pieces which appeared to be single crystals as large as  $4 \times 5 \times 1$  cm could be obtained.

For the comparison the samples were placed as close as possible to the window of a 1P21 photo-multiplier tube operating at about 60 volts per stage. The tube and crystal were kept at room temperature. The pulses were amplified by a wide band linear amplifier<sup>3</sup> equipped with a pulse height selector with which one could conveniently study the size of the pulses.

Using samples of roughly the same size, it was found that gamma-rays from  $\text{Co}^{60}$  produced pulses about three times larger in anthracene than in naphthalene. The counting rate against pulse height selector setting is shown in Fig. 1. Extrapolating the counting rate to zero pulse height, the two materials give nearly the same number of counts, which is in agreement with Deutsch's finding that in these conditions we have 100 percent efficiency for the secondary electrons. However, if one sets the pulse height selector to admit only 10 background counts/sec., the anthracene is 93 percent efficient and the naphthalene only 63 percent. Raising still more the pulse height selector

setting, it is possible to have both a high efficiency and a low background when anthracene is used.

Some experiments with  $\text{C}^{14}$ , emitting beta-rays of 154-kev maximum energy, proved that anthracene responds to electrons of this energy with about the same efficiency as a thin mica window Geiger counter.

Although Kallmann states that he was unable to count alpha-particles with his equipment when using scintillations from naphthalene, we could detect Po alpha-particles both with naphthalene and anthracene. Figure 2 shows the pulse height distribution for the two materials; it is evident that the pulses from anthracene are about five times larger. The extrapolated counting rate was the same as that found with the same source in an argon ionization chamber.

It seemed reasonable to expect that this system would count the recoil protons produced by fast neutrons, and some absorption experiments in Pb were carried out using a Po- $\alpha$ -Be neutron source. The absorption coefficient of Pb for the radiation responsible for most of the counts was  $0.118 \text{ cm}^{-1}$ . This value is much too small for gamma-rays of any energy and is in fairly good agreement with what could be expected for fast neutrons.

The neutrons produce very large pulses, some of which are two times as large as the largest pulses produced by  $\text{Co}^{60}$  gamma-rays. For an anthracene sample 1 cm thick a rough calculation shows that about 10 percent of the fast neutrons striking the anthracene are counted.

\* This document is based on work performed under Contract Number W-35-058 eng-71 for the Atomic Energy Project at Oak Ridge National Laboratory.

<sup>1</sup> H. Kallmann, *Natur und Technik* (July 1947).

<sup>2</sup> Martin Deutsch, M.I.T. Tech. Rep. No. 3.

<sup>3</sup> W. H. Jordan and P. R. Bell, *Rev. Sci. Inst.* 15, 703 (1947).

## Nuclear Reactions of Arsenic with 190-Mev Deuterons

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**B**OMBARDMENT of thin targets of pure arsenic ( $^{75}_{33}\text{As}$ ) with 190-Mev deuterons has led to the observation of nuclear reactions in which some of the product nuclei are more than 20 mass units lighter than the target nucleus. Identification of these and of other reaction products was made by chemical separation of the various radio-isotopes into elemental fractions, followed by an investigation of the radiations associated with each fraction.

The gross rate of decay of the radio-isotopes in each elemental fraction was determined with argon-filled (10 cm pressure) Geiger-Müller counting tubes of the thin window type (*ca.* 3 mg/cm<sup>2</sup> of mica). The half-lives obtained from the resolved decay curves formed the chief basis for identification of known isotopes. In those cases in which sufficient activity was available, samples were placed in a crude beta-ray spectrometer and tested for positive or negative beta-particles.