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Precision Wave-Length and Energy Measurement of Gamma-Rays from Au^{198} with a Focusing Quartz Crystal Spectrometer*

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A RECENT paper[1] describes a precision focusing curved crystal x-ray and gamma-ray spectrometer (2-meter focal length) constructed at the California Institute of Technology. This instrument has now been used to study the 0.41-Mev gamma-ray line from a 1-curie source of the artificial radioactive isotope of gold, Au^{198}, of half-life 2.7 days. The source activitated at Oak Ridge by neutron bombardment consisted of a thin flat strip of gold (dimensions: 0.1 mm by 5.0 mm by 30 mm) placed vertically at the focus of the spectrometer and oriented so that with appropriate lead shielding its thin dimension constituted the "slit" which determined the resolution. The gamma-ray spectrum was studied by moving the source along the focal circle with a precision screw[1] which reads directly in x units (calibrated to high precision and also verified by means of several well-known x-ray lines of much longer wave-length) and by plotting the gamma-ray intensity reflected by the (310) planes of the quartz crystal as a function of screw settings. The gamma-ray intensity was measured with our special multicellular gamma-ray Geiger counter (operating with 4 cells and 5 septa) which, in a somewhat earlier form, has already been described.[1] A more detailed description will be given in a later paper. It has a counting efficiency of about 8 percent for lines in the half-million-volt region. Its operation is now satisfactorily stable and reliable. The multicellular counter is shielded from local radioactivity by 2.5 to 3 inches of lead on all sides. It is "shielded" from cosmic-ray background with six auxiliary anticoincidence counters placed immediately above it, and when no radioactive source is in the spectrometer the residual background with all these precautions is 32 counts per minute.

Figure 1 shows four spectral profiles obtained (in the first order) for the 0.41-Mev gamma-ray line by selective reflection, both to right and to left, from the (310) planes of quartz. If the entire wave-length scale were shown to the same scale as the structure of these line profiles, they would be separated by about thirty times the distance shown in this plot. (The Bragg angle for these lines is about 20 minutes for the (310) planes of quartz $d=1.175$A.) The peaks of the lines are about 4.5 times the background intensity and this ratio, as the strength of the source decays, remains substantially constant until the irreducible background of 32 counts per minute is approached. The background on these curves we believe comes chiefly from scattering of the primary transmitted beam on the partitions of the lead collimator or baffle. The full widths of the lines at half-maximum height are about 0.125 x.u. This width is attributable (1) to the geometrical width of the radioactive source on the focal circle and (2) to the slight aberrations of focus of the curved crystal. These two geometrical width factors are of approximately the same order whereas both the "natural" line width and the quartz (310) plane diffraction pattern width for these hard gamma-rays are undoubtedly much narrower.

Repeated measurements yield the precision values listed in Table I for the wave-length and energy in Mev of this gamma-ray line. The precision measures quoted are "probable errors" computed from the consistency of the above data. It seems likely that any possible systematic errors are much smaller than these probable errors. In computing the above energies in Mev the latest conversion factor[2] $(12394.2\pm0.9)\times10^{-8}$ cm (the wave-length associated with 1 ev) has been used. The conversion factor 1.00203 from the Siegbahn scale of x.u. to absolute units was used.

An exploration has been made for two other softer lines at 0.208 Mev and 0.157 Mev (re-

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[1] Jesse W. M. DuMond, Rev. Sci. Inst. 18, 626 (1947).

[2] J. W. M. DuMond and E. Richard Cohen, Rev. Mod. Phys. 20, 82 (1948).

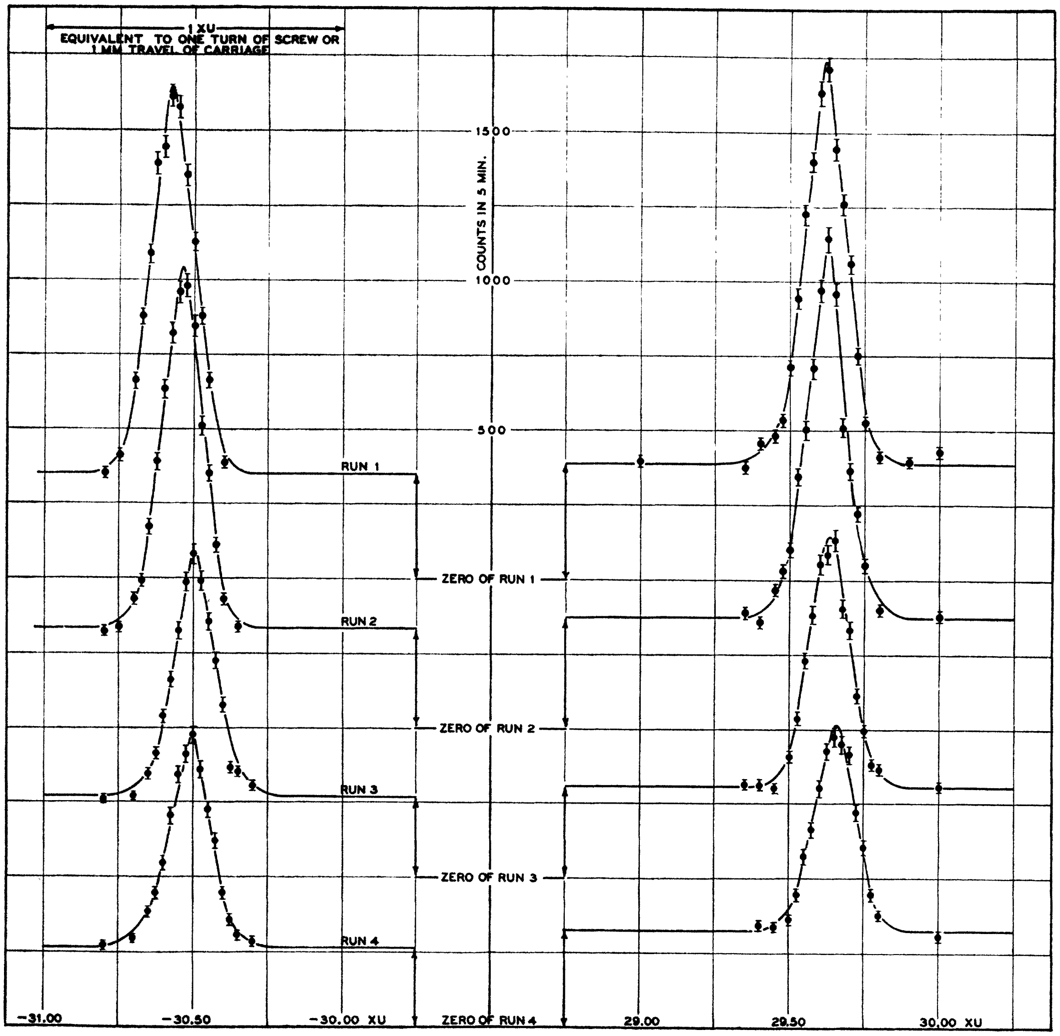

FIG. 1.

ported[3] from this source by β-ray measurements) but these have not been found. These lines, whose intensities were reported to be much lower than the present 0.41-Mev line, would be rendered relatively much weaker still in the present case by self-absorption in our source (thickness, 5 mm), since its specific activity is only about one atom in 10^4. No evidence for heterogeneity of the radiation could be found by absorption measurements with tin in the direct beam but, for the reason stated (self-absorption), this does not conclusively prove the complete absence of the two softer lines.[4]

Careful measurements are being made of the reflection coefficient of the (310) planes of quartz both for the x-ray and gamma-ray region and these results will be published soon. Only about 0.3 percent of the present 0.41-Mev line intensity in the direct beam incident on the crystal is reflected by the crystal planes. This low reflecting power makes the entire method unsuitable for work with weak gamma-ray sources. Sources of the order of 100 mc to 1 curie seem, at present, to be necessary.

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[3] P. W. Levy and E. Grueling, Phys. Rev. **73**, 83 (1948).

[4] A. Mitchell, in a private communication, informs us that he has evidence that these softer lines are due to mercury present as an impurity in the gold when it was irradiated. From our failure to detect the 0.208-Mev line we infer that its intensity is surely less than 12 percent of the 0.41-Mev line. Levy and Grueling's estimate of this intensity ratio was 15 percent.

TABLE I. Preliminary values of wave-length and energy.

Run no.	λ_s – x.u.	λ_g cm	$h\nu$ (Mev)
1	30.095	30.156×10^{-11}	0.41100
2	30.080	30.141	0.41121
3	30.065	30.126	0.41141
4	30.085	30.146	0.41114
5	30.083	30.144	0.41116
	30.082±0.004	30.143±0.004	0.41118±0.00005

Recommended preliminary energy value = 0.4112±0.0001 Mev.

The great advantage of direct crystal spectroscopy of gamma-rays as developed in this instrument is the high precision and high resolution it affords. We hope by means of it to establish a series of accurately determined fixed points on the scale of gamma-ray wave-lengths which can then be used as convenient references in calibrating β-ray spectrometers and in other indirect methods. A precision of two or three parts in ten thousand seems easily indicated for the half-million-volt region and four to six parts in ten thousand for the million-volt region. The study of the spectrum of annihilation radiation will also be attacked shortly.

We believe the present gamma-ray wave-length measurements to be the first high precision measurements ever made by direct crystal spectroscopy in this very short wave-length region.[5] With comparable precision in both, it may now be said that the x-ray region and the gamma-ray region have been joined.

(Note added in proof: We have subsequently shown the two softer lines (0.208 Mev and 0.157 Mev) to be present in our source in about the same intensity ratio as reported by Levy and Grueling. This we did by means of absorption curves in tin with the source turned so that the radiation emerged through the thin dimension to reduce self-absorption. We have also subsequently located and eliminated the cause of the small disagreements in the apparent wave-length position at which the spectral lines occur in the different runs (Fig. 1), a minor mechanical trouble in the front pivot. We believe that a precision better than 1/10,000 may now confidently be expected in the region of 0.5 Mev.

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[5] The first direct crystal spectra of gamma-rays was made in the remarkable and well-known pioneer work of Rutherford and Andrade. The spectrum of radium was also studied with crystals by J. Thibaud and later by M. Frilley. These workers, however, used flat crystals and necessarily sacrificed radically resolving power for intensity. At 35 x.u., for example, Frilley's photographic spectra indicate line widths of the order of 4 x.u. Rutherford and Andrade, Phil. Mag. **27**, 854; **28**, 262 (1914). J. Thibaud, Thesis, Paris (1925); Ann. de physique **5**, 73–152 (1926). M. Frilley, Thesis, Paris (1928); Ann. de physique **11**, 483 (1929).