Counters as described in the foregoing behave like the so-called "slow counters."

Several accounts have been published on discharge mechanism of these counters.[4] It has been pointed out that the discharge spreading along the wire is due to photoelectrons from the cathode. According to Montgomery and Montgomery,[5] this process creates a space charge able to quench the pulse, and the discharge starts again by extraction of electrons from the cathode through positive ions impact.

Following our results on argon plus 0.1 percent carbon dioxide mixture, which probably apply to any counter where the spreading is caused by photoelectric effect, it must be pointed out that only the photoelectric process causes the restarting of the pulse, as the cathodic propagation of the discharge is slow enough in respect to positive ion drift velocity.

In our case, the ion-cathode process does not play an important role in the discharge; the fact that the pulse in the Geiger zone contains about 10^8 charges enables us to conclude that the probability for this process in the studied mixture is less than 10^{-8}.

We gladly thank Professor G. Bolla and Professor B. Ferretti for their helpful discussions.

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Minimum Gamma-Gamma Cross Section in Gold

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IN previous attempts[1–3] to observe scattered photons from (γ, γ) reactions initiated by high energy x-rays, two[1,2] gave negative results and one[3] detected only high energy photons attributed to a Goldhaber-Teller[4] resonance scattering process. The γ-ray decay of a compound nucleus formed by photonuclear excitation could be detected if some of the photon cascades could lead to an isomeric state. The 68-minute Pb^{204m} activity has been excited by x-rays,[5,6] but this could also result from the reaction $Pb^{206}(\gamma, 2n)Pb^{204m}$. We have measured the activation curve for the reaction $Au^{197}(\gamma, \gamma)Au^{197m}$. Since gold contains only one isotope, the 7.5-second isomer can be excited only by the above reaction.

A relative activation curve was obtained using a dropping apparatus described elsewhere.[7] Absolute activities resulted from normalization against the known $Cu^{63}(\gamma, n)Cu^{62}$ reaction,[8] and from correction for external and internal absorption of the three Au^{197m} conversion electrons.[9] Weakness of the 7.5-second activity prevented the activation shape from being determined as accurately as usual, but the accuracy was sufficient for a computation of the general shape of the cross-section curve by the photon difference method.[10] The cross-section curve is shown in Fig. 1. The absolute values are subject to uncertainties in the absorption corrections and in the conversion coefficients, but they should be correct to within a factor 2.

An additional 30-second activity was observed at the higher x-ray energies, which was produced to the same extent in gold samples of very high but different purities. No likely end product of a photonuclear reaction in gold is known to have this half-life. The activation curve suggests that a charged particle is emitted in the unknown reaction.

No observable short-lived activities in the gold were produced in irradiations with fast neutrons. The neutron contamination of the x-ray beam thus could not have contributed appreciably to the Au^{197m} yield due to inelastic scattering.

The (γ, γ') cross-section curve of Fig. 1 is similar in shape below 15 Mev to that for the $Ta^{181}(\gamma, n)Ta^{180}$ reaction;[9,10] the half-width of the latter is smaller, probably due to "cascade" competition

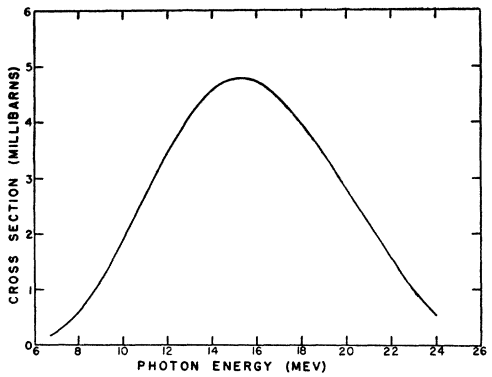

FIG. 1. Cross-section curve for the reaction $Au^{197}(\gamma, \gamma')Au^{197m}$. This is a minimum cross section; ground-state transitions and $(\gamma, \gamma'n)$ reactions are not detected. The peak value of 5 millibarns occurs at 15 Mev, the half-width is 10 Mev, and the integrated cross section is 0.05 Mev-barns.

with the $(\gamma, 2n)$ reaction. The reaction $Au^{197}(\gamma, n)Au^{196}$ is expected[11] to have a peak cross section of 500 millibarns near 15 Mev. The ratio of (γ, γ') to (γ, n) cross sections in gold thus has the unexpectedly large minimum value of 0.01.

The true (γ, γ') to (γ, n) cross-section ratio is probably much larger than this. If the nucleus is excited by photons in a dipole interaction,[4,12] there will be many more paths by which decay by photon cascades can lead to the ground state than to the isomeric state of considerably different spin. The product nuclei for (γ, n) reactions in Br^{81}, Zr^{90}, and Mo^{92} have isomeric states; measurements of these reactions in this laboratory show that the presumably smaller spin change between target and product nucleus is favored by factors from 3 to 5. It is therefore not unreasonable to guess that the total (γ, γ') cross section in Au^{197} has a peak value of the order of 25 millibarns.

The radiation width for electric radiation of multipole order l is given[13] as

$$\Gamma_\gamma{}^{(l)}=\frac{2(l+1)(2l+1)}{l[(2l+1)!!]^2}\frac{e^2}{\hbar c}\left(\frac{R}{\hbar c}\right)^{2l}\frac{1}{D_0}\times\int_0^E(\hbar\omega)^{2l+1}\frac{\omega_l(E-\hbar\omega)}{\omega_l(E)}d(\hbar\omega), \quad (1)$$

where E is the excitation energy, D_0 the spacing between low-lying levels ($\sim$0.5 Mev), $\omega_l(E)$ the level density at excitation E, and $(2l+1)!!=1.3.5\cdots(2l+1)$. Magnetic radiation widths are smaller than electric ones of the same multipole order by a factor $(\hbar/McR)^2$. Radiation widths for dipole and quadrupole emission from Au^{197} with $E=15$ Mev are listed in Table I. From statistical theory[14] we calculate the neutron emission width to be $\Gamma_n=100$ electron volts for the same excitation. The large (γ, γ') to (γ, n) cross-section ratio cannot result from magnetic dipole and electric quadrupole radiation, but is of the right order of magnitude to result from electric dipole radiation. At low excitations electric dipole radiation widths are much less than calculated from Eq. (1), owing to very small nuclear electric dipole moments. Thus, the agreement obtained here may be taken as additional support for the electric dipole interaction theories[4,12] at higher excitations.

TABLE I. Radiation widths for decay of Au^{197} from 15-Mev excitation, computed from Eq. (1) with $\omega_l(E-\hbar\omega)=\text{const}\ \exp\ 2\,[9.5(E-\hbar\omega)]^{\frac{1}{2}}$. The second column gives the partial radiation width for emission of 7- to 15-Mev photons (which cannot be followed by neutron emission); the third column gives the total radiation width for emission of photons of any energy. Widths are in electron volts.

Type of radiation	$\Gamma\gamma$ for $7\leqslant\hbar\omega\leqslant15$	$\Gamma\gamma$ for $0\leqslant\hbar\omega\leqslant15$
Electric dipole	12	170
Magnetic dipole	2.4×10^{-3}	3.3×10^{-2}
Electric quadrupole	0.07	0.3
Magnetic quadrupole	1.4×10^{-5}	6×10^{-5}

The energy distribution of the initial photons given by the integrand of Eq. (1) is strongly peaked at low photon energies. Thus, at the end of several steps of a typical photon cascade, neutron emission will be possible, removing such nuclei from detectability in this experiment. We estimate that the decay of the gold nucleus can proceed by initial photon emission in as many as one-third of the photonuclear excitations.

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Conductivity of the Sodium Tungsten Bronzes*

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RECENT work by Straumanis and Dravnieks[1] and Huibregtse, Barker, and Danielson[2] has shown that the cubic sodium tungsten bronzes (Na_xWO_3, where x varies between 0.95 and 0.3) have high electrical conductivity. These workers found a positive temperature coefficient of resistivity, but the conclusion that the conductivity was metallic in nature was not justified by their data, which did not show a linear dependence of resistivity upon temperature. This linear temperature dependence would be expected from the free electron model proposed by Stubbin and Mellor[3] and Kupka and Sienko[4] on the basis of magnetic susceptibility measurements. The magnitude of the conductivity reported previously appeared too low to fit in with a free electron picture, and gave a value for the mobility of electrons, as calculated by Huibregtse, *et al.*, which was smaller than that of metallic sodium by a factor of twenty-four.

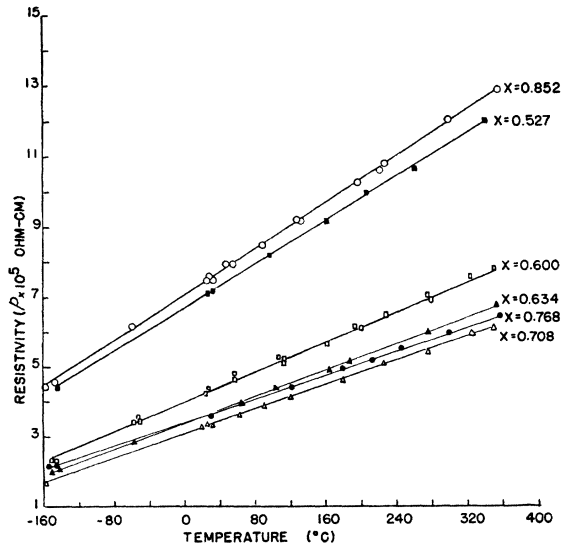

FIG. 1. Plot of resistivity *vs* temperature for six compositions of sodium tungsten bronze, Na_xWO_3.

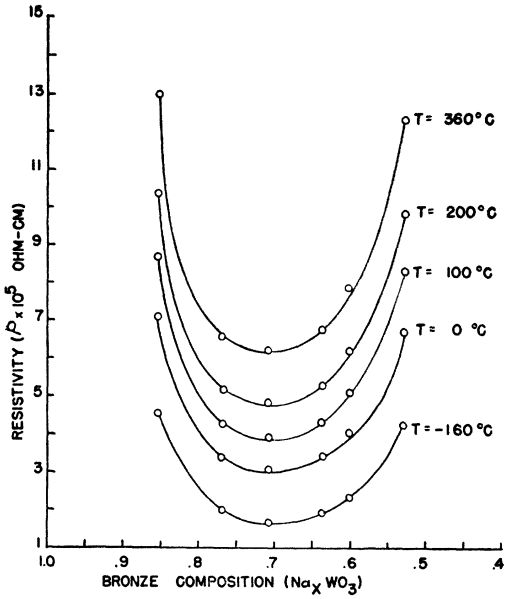

FIG. 2. Resistivity isotherms for various sodium tungsten bronzes.

The measurements reported here were made by a potential probe method (to eliminate contact effects) over a temperature range of −160° to +360°C, for single crystals of six different compositions. The results, shown in Fig. 1, indicate a linear temperature dependence of resistivity over the entire temperature range studied. This is quantitative confirmation of the metallic nature of conduction in these materials. Using our value for the conductivity of $Na_{0.708}WO_3$(3.0×10^4 ohm^{-1}-cm^{-1} at 25°C) and the value obtained by Huibregtse, *et al.* for the Hall coefficient of $Na_{0.685}WO_3$(-5.3×10^{-4} cm^3/coulomb at 25°C), we obtain an electron mobility of 16 cm^2/volt-sec as compared with 2c m^2/volt-sec calculated by Huibregtse, *et al.* and 48 cm^2/volt-sec reported for metallic sodium. It appears that the mobility of electrons in these bronzes is approximately 35 percent of their mobility in metallic sodium.

In Fig. 2 a series of resistivity isotherms is shown as a function of bronze composition. The compositions were determined by x-ray analysis of powdered bronzes heated in contact with a single crystal until composition equilibrium was obtained. These compositions have lattice constants that fall on the linear portion of a lattice constant—composition curve of a previously prepared series of powdered bronzes.[5] These isotherm curves show a minimum in resistivity at approximately $x=0.70$. The temperature coefficients of resistivity behave in a similar manner (Table I).

We propose a tentative interpretation of this resistivity minimum in terms of equilibrium between undissociated sodium atoms and sodium ions plus free electrons. In the region below $x=0.70$ each sodium atom introduced contributes one free electron and one random scattering center (Na^+); while above $x=0.70$ the addition of undissociated sodium atoms contributes only additional scattering centers. These additional scattering centers are

TABLE I. Resistivity of sodium tungsten bronzes $-Na_xWO_3$.

Composition	Resistivity Temp. (°C)	$\rho\times10^5$	Temp. coef. of resist. ohm-cm per °C
$x=0.852$	26.5	7.50 ± 0.04	16.33×10^{-3}
$x=0.768$	27.5	3.65 ± 0.03	8.75×10^{-3}
$x=0.708$	29.0	3.34 ± 0.02	8.40×10^{-3}
$x=0.634$	27.0	3.67 ± 0.03	9.38×10^{-3}
$x=0.600$	26.0	4.50 ± 0.04	10.62×10^{-3}
$x=0.527$	31.0	7.18 ± 0.02	15.66×10^{-3}