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CONVERSION OF γ-RAYS INTO UV-LIGHT

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The apparatus for the measurement of the efficiency of the conversion of γ-rays into UV-light has been devised. The conversion system consists of helium gas with a drop of mercury. The G-value of UV-light-photons at 253.7 nm produced in this system by γ-irradiation was estimated both experimentally and theoretically. The mercury photosensitized decomposition of nitrous oxide at 0 °C was used as the actinometer. The efficiency of the conversion of ^{60}Co γ-rays into UV-light at 253.7 nm was found to be 80 %.

If a 1.25 MeV γ-ray-photon is ideally converted into 5 eV UV-light-photons, one γ-ray-photon should give 2.5×10^5 UV-light-photons. Such a converting system is a kind of scintillator. However, the efficiency of the scintillators widely used at present does not exceed a few percent; i.e., the G-value is less than unity.

Recently, we have theoretically calculated the G-values for ionizations and excitations in noble gases from helium to xenon irradiated by 100 keV electrons. The G-values obtained were in good agreement with the experimental data.[1] This calculating method can easily be applied to the mixture of two noble gases.[2] If we can assume that a mercury atom has only two 6s electrons and that their parameters needed for the calculation are those shown in Table 1, we can estimate the G-values for ionizations and excitations in the mixture of helium and mercury vapor. The system we calculated is the mixture of 1 atm of helium and 10^{-3} Torr of mercury. The G-values obtained are listed in Table 2. Here, the triplet excitation of mercury ($6^3P_1 \leftarrow 6^1S_0$) was treated as an allowed transition.

Table 1. The parameters for mercury atoms (eV).

Ionization potential	10.4
Singlet excited state	6.7
Triplet state	4.9
Average kinetic energy	20.8

If such a reaction system is really operated, so-called Jesse effect will occur[3] and the following reactions have to be considered.

Table 2. The G-values for ionizations and excitations.

	Ionization	Excitation	
		singlet	triplet
helium	2.3	0.9	0.2
mercury	0.3	1.3	3.2

$$He^+ + Hg \longrightarrow He + Hg^+ \quad (1)$$

$$^3He^* + Hg \longrightarrow He + Hg^+ + e^- \quad (2)$$

$$^1He^* + Hg \longrightarrow He + Hg^+ + e^- \quad (3)$$

The lifetime of $^1He^*$ is very short; however, the imprisonment will prolong its apparent lifetime. Ultimately the neutralization reaction occurring in this system will be between Hg^+ ions and electrons. If a quarter of the neutralization reaction produces the singlet excited state, $^1Hg^*$, and three quarters give the triplet state, $^3Hg^*$, the total G-value of $^3Hg^*$ should be 6.0. As Table 2 shows, a large portion of $^3Hg^*$ is produced in the collision with sub-excitation electrons in helium. Since the ideal conversion of γ-rays into the $^3Hg^*$ state corresponds to $G(^3Hg^*) = 20.4$ (= 100/4.9), the conversion efficiency theoretically calculated is 29 %.

In order to measure the efficiency of such a converter, we have devised a reaction vessel, which is schematically shown in Fig. 1.

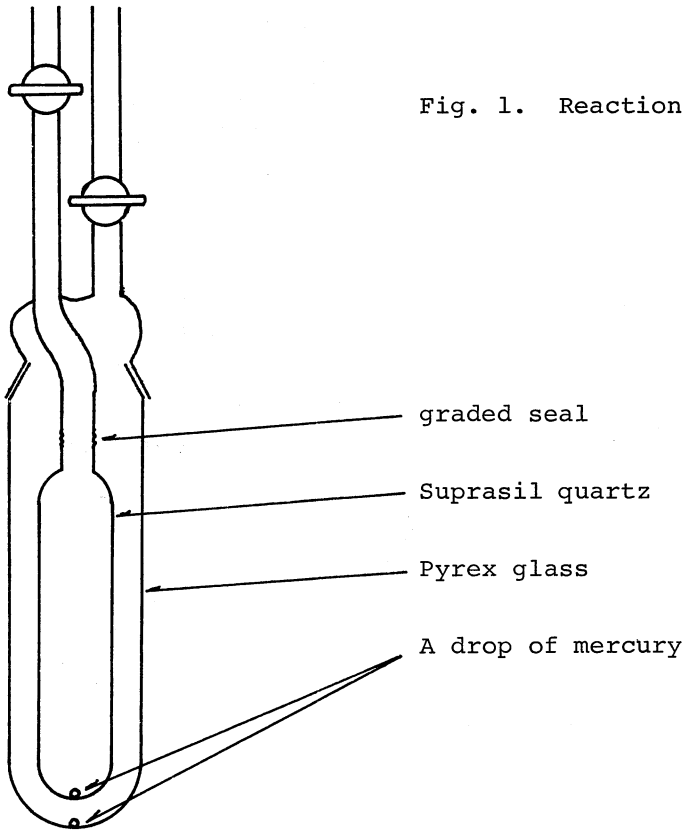

Fig. 1. Reaction vessel.

The inner tube is made of Suprasil quartz which is transparent for the UV-light at 253.7 nm even after the γ-irradiation. The transmission was 92 % at 253.7 nm. The outer tube is made of Pyrex glass. The joint attached to the outer tube is for annealing the Suprasil quartz tube irradiated by γ-rays; however, the transparency at 253.7 nm was not changed even after γ-irradiation. At the shorter wavelengths, the transparency was reduced by γ-irradiation.

As the reaction system, we took the mixture of 50 Torr N_2O and 2.5 Torr ethylene, which was introduced in the outer tube. The G-value of nitrogen from this mixture at 0 °C is known to be about 8.[4] When 1 atm helium with a drop of mercury was present in the inner tube, the formation of nitrogen was increased. This increase is probably due to that the mercury resonance line at 253.7 nm from the inner tube gives rise to the mercury photosensitized decomposition of N_2O in the outer tube. The quantum yield of nitrogen in the mercury photosensitized decomposition of N_2O in the presence of a small amount of ethylene is known to be unity.[5] The experimental results are summarized in Table 3.

Table 3. The yield of nitrogen from the mixture of nitrous oxide (50 Torr) and ethylene (2.5 Torr). The irradiation time is 10 hr with the dose rate of 4.2×10^5 R hr^{-1}.

helium in the inner tube (Torr)	nitrogen (μmol)
0	0.36 ± 0.02
760	0.89 ± 0.02

The data is the average of three pairs of experiments. By using the formation of nitrogen from nitrous oxide as a dosimeter,[6] the total dose absorbed by helium was estimated to be 2.16×10^{18} eV. Consequently, the G-value of UV-light-photons at 253.7 nm produced in this converting system may be estimated as follows:

$$G(\text{UV-light-photons}) = \frac{(0.89 - 0.36) \times 10^{-6} \times 6.023 \times 10^{23}}{2.16 \times 10^{18} \times 0.92} \times 100$$

$$= 16.1$$

This value is much larger than the theoretically calculated value, 6.0.

Several reasons for this discrepancy can be considered.

1) In the present treatment, the contribution of $^1Hg^*$ has not been taken into account. The mercury ($^1P_1$) photosensitized decomposition of nitrous oxide has not been reported. If we assume that the quantum yield of nitrogen in the mercury ($^1P_1$) photosensitized decomposition of nitrous oxide is unity and that the Suprasil quartz is transparent for the resonance line at 184.9 nm, the G-value of nitrogen theoretically calculated will increase to 8.2. This is obviously not enough to explain the experimental result.

2) Reactions (2) and (3) are the Penning ionization reactions. The electrons ejected in these reactions should have an excess energy, which is large enough to excite two mercury atoms into the $^3P_1$ state. If this process is taken into account, another 2.2 have to be added to the theoretical G-value. This is again not enough to explain the experimental result.
3) There are many approximations on the basis of which the theoretical calculation has been made. Especially, the cross section formulated for the excitation process is not a good approximation, although the alternative formulation is not available at present. Probably this is one of the main reasons for the discrepancy between experiment and theory.

Further investigations are being carried out.

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