The Utilisation of the Fricke Dosimeter for Evaluating the Biological Radiation-protective Potential of Water-soluble Organic Compounds

By G. G. JAYSON
(*Chemistry Department, Liverpool Regional College, Byrom Street, Liverpool*)
and ANTONY C. WILBRAHAM*
(*Chemistry Department, Florida Presbyterian College, St. Petersburg, Florida* 33733)

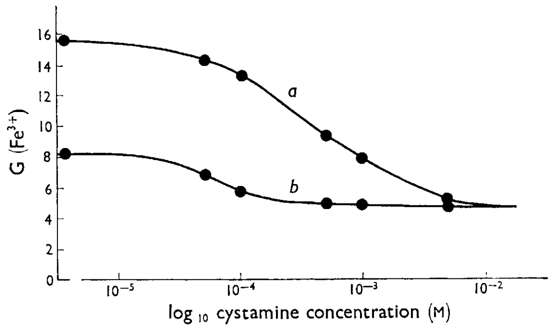
WHILE the presence of organic impurities in Fricke dosimeter solutions[1,2] during irradiation usually leads to increased ferric yields,[3] the addition of cystamine produces a marked decrease. Cystamine is among the best of the known biological radiation-protective compounds.

This result forms the basis for our method of protection evaluation and is further supported by the results from some more recent experiments, using cysteamine and both oxidized and reduced glutathione. These latter compounds are known radiation protective substances—and all reduce radiolytic ferric yields when present in Fricke solutions during irradiation.

Fricke dosimeter solutions containing cystamine sulphate (0·01—10 mM) were prepared and irradiated with *X*-rays (250 pkv, 15 mA, dose-rate 958 rads/min.) under both aerated and deaerated conditions.

From the yield (ferric) *vs.* dose (total) curves, all of which were linear through the origin, $G(Fe^{3+})$ values were calculated and plotted as a function of the concentration of added cystamine (Figure). A common limiting value of $G(Fe^{3+}) = 4{\cdot}5$ was obtained for both the aerated and deaerated systems.

The reactions during the radiolytic oxidation of ferrous ions are well understood[2,4] and the rate constants for the individual reactions are known.[5] Since, under the conditions of irradiation, cystamine does not react with hydrogen peroxide,[6] it follows that interference must be with the Fe^{2+} *vs.* $\cdot OH$ and Fe^{2+} *vs* $\cdot O_2H$ interactions. Cystamine has been demonstrated to react readily with $\cdot OH$[6] and also, at high concentrations, with $\cdot O_2H$ radicals.



Dependence of ferric ion production, from irradiated ferrous ammonium solutions (Fricke solutions) upon the $\log_{10}$ *of the concentration of added cystamine.*

The following interpretation is proposed to account for the present observations and particularly the numerical value of the limiting ferric yield, at high cystamine concentrations, in the presence or absence of oxygen:

Oxygen present:

$$H^+ + \cdot O_2H + RS\cdot SR \rightarrow R\overset{\cdot}{S}\cdot\overset{+}{S}R + H_2O_2 \quad (1)$$

Oxygen absent:

$$H^+ + H\cdot + Fe_2{}^+ \rightarrow Fe^{3+} + H_2 \quad (2)$$

then in both cases:

$$H_2O_2\dagger + Fe_2{}^+ \rightarrow Fe^{3+} + OH^- + \cdot OH \quad (3)$$

$$\cdot OH\ddagger + RS\cdot SR \rightarrow RS\cdot\overset{+}{S}R + OH^- \quad (4)$$

$$R\overset{\cdot}{S}\cdot\overset{+}{S}R \rightarrow \text{products} \quad (5)$$

Under both sets of conditions the limiting $G(Fe^{3+})$ is given by the expression:

$$G(Fe^{3+}) = G_{H\cdot} + G_{H_2O_2} \textit{ i.e. } 3{\cdot}7 + 0{\cdot}8 = 4{\cdot}5$$

As a test for the above proposals, the deaerated system was considered; a cystamine concentration exists at which half of the $\cdot OH$ radicals react with cystamine and half react with ferrous ions, *i.e.* only partial scavenging by cystamine occurs, therefore:

$$G(Fe^{3+}) = G_{H\cdot} + \tfrac{1}{2}\,G_{\cdot OH} + \tfrac{3}{2}\,G_{H_2O_2}$$

$$\textit{i.e. } 3{\cdot}7 + \tfrac{1}{2}(2{\cdot}7) + \tfrac{3}{2}\,(0{\cdot}8) = 6{\cdot}25$$

From the Figure it is seen that this $G(Fe^{3+})$ value occurs in 1mM-ferrous solution at 0·08 mM cystamine.

The ratio of the rate constants for reaction of $\cdot OH$ with cystamine and of $\cdot OH$ with ferrous ions[7] must be the inverse of this concentration ratio ($\sim$ 12 : 1) which is in general agreement with the known[8] rate constants of sulphur compounds with $\cdot OH$ (3—9 $\times$ 10^9M^{-1} sec.$^{-1}$) and in good agreement with the value (5—9 $\times$ 10^9M^{-1} sec.$^{-1}$) obtained by us in preliminary pulse radiolysis studies.

In aerated systems, containing 1mM-ferrous and 1mM-cystamine, virtually all the $\cdot OH$ radicals will be scavenged by cystamine, while the $\cdot O_2H$ radicals will react with ferrous ions.[6] Theoretically, $G(Fe^{3+})$ should equal $2G_{H\cdot} + G_{H_2O_2}$ or 8·2, a value in excellent agreement with that observed experimentally (*ca.* 8·0, Figure).

We thank the City of Liverpool Education Authorities for support of this work and for a Research Assistantship (to A.C.W.).

(*Received, April 2nd*, 1968; *Com.* 407.)

† In the aerated system H_2O_2 includes both the radiolytic yield and the yield from reaction (1).
‡ $\cdot OH$ includes both the radiolytic yield and the yield from reaction (3).

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