

To 10 cc. of approximately neutral cobalt solution containing about 0.5 mg. of cobalt, and also to 10 cc. of standard cobalt solution containing exactly 0.5 mg. of cobalt,<sup>2</sup> add 3 cc. of arsenophosphotungstic acid reagent. Invert once. Add 4 cc. of the cyanide solution from a buret. Invert both tubes once simultaneously. Compare the standard and unknown blue solutions in a colorimeter. For best results the colorimetric reading should be made from two to ten minutes after inversion of the tubes. The ratio of the reading of the standard to the reading of the unknown, multiplied by 0.5 gives the mg. of cobalt in 10 cc. of unknown solution. The colors obtained match exactly. No turbidity develops even after twenty-four hours of standing. Nickel does not interfere with this test except that if the 10 cc. of solution contains more than 5 mg. of nickel, nickel cyanide tends to be precipitated when the cyanide is added. If more cyanide is used (*i. e.*, 6-8 cc.), more nickel can be kept in solution, but the tendency to turbidity is increased. In the presence of up to 5 mg. of nickel, the readings are accurate to within about 1% (0.005 mg. of cobalt). The ions mentioned above which interfere with the qualitative reaction must be absent. There is another group of metallic ions which, although not giving the test directly, may interfere if present in appreciable amounts (*i. e.*, more than 4 or 5 times the concentration of cobalt) by yielding a turbid solution. This group includes NH<sub>4</sub>, Mg, Ca, Sr, Ba, Sn, Sb, As, Cd, Bi, Pb, Ag. Finally, it should be noted that colored solutions of manganese and chromium obviously interfere with the proper color readings between standard and unknown.

The essential accuracy of this method was demonstrated by the determination of the cobalt present in pure cobalt solutions and in potassium cobaltinitrite precipitates (after converting the cobaltinitrite to a cobaltous salt by heating with *N* hydrochloric acid. The results obtained in a long series of determinations in the latter case showed a maximum deviation from the theoretical of 1.5%, with an average deviation of about 0.5%.

In conclusion the writer wishes to express his indebtedness to Professor S. R. Benedict, whose help has been essential to the completion of this work.

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[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY OF THE UNIVERSITY OF ILLINOIS]  
**SOME NEW EXPERIMENTS ON THE CHEMICAL EFFECTS OF  
X-RAYS AND THE ENERGY RELATIONS INVOLVED**

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Although the photochemical action of x-radiation is of interest because of its possible significance in interpreting the physiological effects, very few studies in this field have been made until recently. Within the last two years, however, the oxidation of ferrous to ferric sulfate has been studied by Fricke and Morse,<sup>1</sup> oxyhemoglobin to methemoglobin by Fricke and Petersen,<sup>2</sup> the inversion of sugar by Reinhardt and Tucker,<sup>3</sup> and the

<sup>2</sup> If less than 0.5 mg. of cobalt is available, the volume of solution and of reagents used can be reduced correspondingly.

<sup>1</sup> Fricke and Morse, *Am. J. Roentgenology & Radium Therapy*, **18**, 426-430 (1927).

<sup>2</sup> Fricke and Petersen, *ibid.*, **17**, 611-620 (1927).

<sup>3</sup> Reinhardt and Tucker, *Radiology*, **12**, 151-153 (1928).

decomposition of iodoform,<sup>4</sup> hydrogen peroxide and potassium persulfate<sup>5</sup> by Glocker. These researches have established the facts that the photochemical action is very small and is independent of the wave length of the radiation within limits of about 0.2 to 0.8 Å. Studies of the coagulatory action of x-rays on colloids have been carried on recently by Fairbrother and co-workers.<sup>6</sup>

TABLE I

RESULTS OF EXPERIMENTS ON CHEMICAL EFFECTS OF X-RADIATION OF EFFECTIVE WAVE LENGTH 0.24 Å.

Initial substance	Change	Remarks
Anthracene	No change in 200 hours	
Dianthracene	No change in 200 hours	
Maleic acid	No change in 200 hours	
Fumaric acid	No change in 200 hours	
Iodine and benzene	Absorption of iodine 6.5%	
Ferrous sulfate	40% oxidation to ferric	Agreement with Fricke's result
Ferric sulfate	No change	Kailan reported slight reduction by radium rays
Potassium iodide	Iodine freed } O <sub>2</sub> and KNO <sub>2</sub> } I <sub>2</sub> and KI } MnO <sub>2</sub> }	Quantitative results below
Potassium nitrate		
Potassium iodate		
Potassium permanganate		
Methylene blue in acetone	No change	Effects of presence of colloidal lead and lead nitrate, and of simultaneous irradiation with ultraviolet and x-rays presented below
Sucrose	Slight inversion	
Dyes		
Triphenylmethane	No change	
Diphenylmethane		
Azoindigo		
Condensation		
Benzaldehyde + benzaldehyde		5% in 5 hours of raying
Benzaldehyde + acetophenone		35%
4-Hydroxy-benzaldehyde + acetophenone		75%
4-Hydroxy-benzaldehyde + benzaldehyde		19%
Acetone + acetaldehyde		Very small
Piperonal + acetophenone		14%
Colloid coagulation		
Pb	Stabilized	
Albumin	Coagulated	
Clay	Coagulated	Pure kaolin unaffected

<sup>4</sup> Baumeister and Glocker, *Z. physik. Chem.*, **97**, 368 (1921).

<sup>5</sup> Glocker and Risse, *Z. Physik*, **48**, 845-851 (1928).

<sup>6</sup> Crowther and Fairbrother, *Phil. Mag.*, [7] **4**, 325-335 (1927); Fairbrother, *Brit. J. Radiology*, [N. S.] **1**, 121-125 (1928); *Phil. Mag.*, [7] **6**, 385-401 (1928).

The present researches were undertaken in order to determine what types of reactions are sensitive to radiation and, secondly, to study the energy relations involved. In order to satisfy the first point, a number of reactions were investigated. The procedure followed in general was to expose the specimen in a thin-walled pyrex bulb to polychromatic radiation from a tungsten target of effective wave length  $0.24 \text{ \AA}$ . at a distance of eight inches from the focal spot. In each case a control of a similar bulb treated in the same manner but protected from radiation by a lead shield was used. The qualitative results obtained are shown in Table I.

### Details of Experiments on Chemical Changes by X-Rays

**Ferrous Sulfate  $\rightarrow$  Ferric Sulfate.**—A 10-cc. solution of ferrous ammonium sulfate in  $0.04 \text{ N H}_2\text{SO}_4$  was exposed to x-rays from a molybdenum tube for twenty hours and then titrated with  $0.01010 \text{ KMnO}_4$ : exposed, 8.18 cc. required; blank, 5.85 cc. required. Experiments in which sealed bulbs of ferric sulfate were given exposures of several months gave negative results.

**Anthracene  $\rightarrow$  Dianthracene.**—A saturated solution of anthracene in phenetole was exposed to radiation for forty-six hours with no effect.

A saturated solution of anthracene in xylene was exposed for several hours to ultraviolet light from a mercury arc in quartz and a considerable precipitate of dianthracene was formed. A portion of the original solution of anthracene sealed in a bulb, and a second bulb containing a suspension of the dianthracene formed in xylene, were exposed to over 150 hours of raying and no apparent change in either took place.

**Iodine and Benzene.**—A solution of iodine in benzene sealed in a bulb was exposed to x-rays. One-cc. samples of this and of a similar sample unexposed were titrated with sodium thiosulfate. Results—cc. of  $0.10 \text{ N Na}_2\text{S}_2\text{O}_3$  used: unexposed, 35.70, 35.70; exposed, 32.37, 32.27.

**Acetone, Iodine and Water.**—Apparently unaffected by x-rays. The high temperature coefficient makes this reaction impracticable for study.

**Inversion of Sugar in the Presence of Lead Nitrate.**—The presence of lead nitrate apparently aids the inversion of sugar under the action of x-rays but the effect is probably secondary due to a change in  $P_H$ . Results obtained after twenty-three hours of exposure to radiation from a tungsten target tube at 75,000 volts and 4 to 5 milliamperes lasting over an interval of one week were as follows.

Solution	Saccharimeter reading at $20^\circ$	$P_H$
Sugar solution unexposed	38.8	5.8
Sugar solution exposed to x-rays	38.4	5.8
100 cc. of sugar solution + 1 cc. of 10% $\text{Pb}(\text{NO}_3)_2$	38.2	5.8
100 cc. of sugar soln. + 1 cc. of 10% $\text{Pb}(\text{NO}_3)_2$ exposed to x-rays	36.4	$4.4 < P_H < 5.2$

### Condensations of Aldehydes and Ketones

Reactions in the field of organic chemistry offer many opportunities for the study of the effects of x-radiation with the possibility that much larger changes may be observed than in the examples of inorganic compounds thus far considered. As one promising type was chosen the condensation reaction of aldehydes and ketones, particularly on account of

the known photochemical reactions of formaldehydes to form sugars. Claisen and Claparède<sup>7</sup> prepared phenylstyryl ketone by mixing benzaldehyde and acetophenone in equal proportions, saturating with hydrogen chloride gas and allowing to stand in the cold for twelve hours. The hydrogen chloride was then removed from the product by heating the mixture on the water-bath for several hours. The ketone so produced was crystallized from petroleum ether with a yield of 32%. While this reaction has the disadvantage that it will proceed without radiation, it was thought that there might be a distinct catalytic effect in irradiation. Accordingly two samples of each of the several mixtures were placed in exactly the same place, at 50°, one being entirely protected by lead as a control and the other exposed to x-rays from a tungsten target tube with an effective wave length of 0.24 Å. for a period of five hours.

## RESULTS OF SERIES OF EXPERIMENTS

No.	Aldehyde	G.	G.	HCl	Product				
					Exposed to x-rays G.	%	Control G.	%	
1 <sup>a</sup>	Benz-	15	Acetophenone	15	2 g.	10.5	35	7.0	23
2	4-OH-Benz-	1	Acetophenone	1	5 drops	1.5	75	1.2	60
3	4-OH-Benz-	1	Benzaldehyde	1	5 drops	0.38	19	0.27	13.5
4 <sup>b</sup>	Benz-	30	.....	..	1 cc. (concd.)	1.5	5	1.4	4.7
5 <sup>c</sup>	Piperonal	5	Acetophenone	Excess	10 drops	1.4	14	0.6	6
6	Acetal-	..	Acetone.—Two samples were treated in similar manner but only a small amount of dark red oil was formed, probably due to the formation of para-acetaldehyde.						
7	Salicyl-	..	Acetophenone.—The product formed only with exposure to x-rays is a dark red oil, and not chalcone, which the usual condensation gives. The oil could not be crystallized from alcoholic solution.						

<sup>a</sup> Benzaldehyde + acetophenone  $\longrightarrow$  phenyl styryl ketone ( $C_6H_5CH=CHCOC_6H_5$ ).

<sup>b</sup> Melting point of product 125°, probably stilbene,  $C_6H_5CH=CHC_6H_5$ .

<sup>c</sup> Melting point of product (both) 119–120°, colorless needles.

Summarizing the results of these reactions, it may be concluded that the condensation of aldehydes with ketones is markedly catalyzed by x-radiation, while the condensation of aldehyde with aldehyde is affected not at all or to only a small extent by the rays.

It is evident from many of these results that sensitivity to ultraviolet light is no criterion for prophesying a sensitivity to radiation in the region of 0.2–0.3 Å. The second conclusion to be noted is that the reactions most affected are those which involve oxidation in aqueous solution.

The above results shed no light on the question of the physiological action of x-rays. No chemical action yet studied, with the exception of the reduction of the silver bromide on a photographic plate, the oxidation of ferrous sulfate and possibly of the new aldehyde and ketone conden-

<sup>7</sup> Claisen and Claparède, *Ber.*, **14**, 2463 (1881).

sation reactions presented in this paper, is of the same order of magnitude as that change which occurs in body tissue. It is possible that some chemical reaction sensitive to radiation, whose counterpart has not yet been discovered, may underlie physiological action, or that the latter depends on such an effect as the coagulation of a colloid. Several examples of the latter were investigated such as the coagulation of egg albumin and of colloidal clays, which give changes of larger magnitude than those observed in the case of chemical reactions. Further studies were discontinued inasmuch as several recent papers by Fairbrother have appeared on the subject.

### A Test of the Theory of Hydrogen Peroxide Formation in the Photochemical Oxidation of Potassium Iodide and the Reduction of Potassium Nitrate

Inasmuch as experiments by Glocker have shown that x-radiation influences the decomposition and also the formation of hydrogen peroxide, it seemed possible that the oxidations noted in aqueous solution were merely secondary reactions following the production and subsequent decomposition of hydrogen peroxide from water and oxygen. The following set of experiments was designed to test this hypothesis.

1. Two thin-walled pyrex tubes were filled with a 2% potassium iodide or 0.1 *M* potassium nitrate solution. Through the following devices one was kept saturated with oxygen while the other was freed of the gas, and both were exposed to the same dose of radiation.

(a) One was boiled to expel oxygen, cooled in a nitrogen atmosphere and sealed. The other was provided with an outlet into an absorption bulb of potassium iodide not exposed to the radiation, and a slow stream of oxygen or air bubbled through during the exposure.

(b) One was heated at 100° to expel oxygen and sealed at that temperature; the other was saturated with oxygen at 0° and sealed.

The experimental data, which are illustrated by the accompanying graph, Fig. 1, revealed the following facts. (1) The decomposition of potassium iodide in the *absence* of oxygen is a straight line function of the dosage of radiation. (2) The decomposition of potassium iodide in the *presence* of an excess of oxygen takes place to a larger extent, and is not in direct proportion to the amount of radiation. (3) The decomposition of potassium nitrate is a straight line function of the dosage of radiation, and is independent of the presence of oxygen. (4) The ratio of molecules of potassium nitrate to molecules of potassium iodide decomposed by the same amount of radiation is 2.90.

The following conclusion might, therefore, be drawn from the data: the decomposition of potassium iodide in the first case (absence of oxygen) is independent of any hydrogen peroxide mechanism which requires the

presence of oxygen. Even if the objection should be raised that a very slight amount of oxygen might have been retained by the water under experimental conditions, the direct proportionality between dosage of radiation and amount of change would indicate that the concentrations of the initial reactants do not change appreciably, a condition which is true for the water and potassium iodide but not for the oxygen. The reaction occurring would seem to be



Though this reaction would involve a large increase in free energy, the amount of energy absorbed in the radiation is much greater. The production of hydrogen from water under the radiation by x-rays has been noted by Fricke.

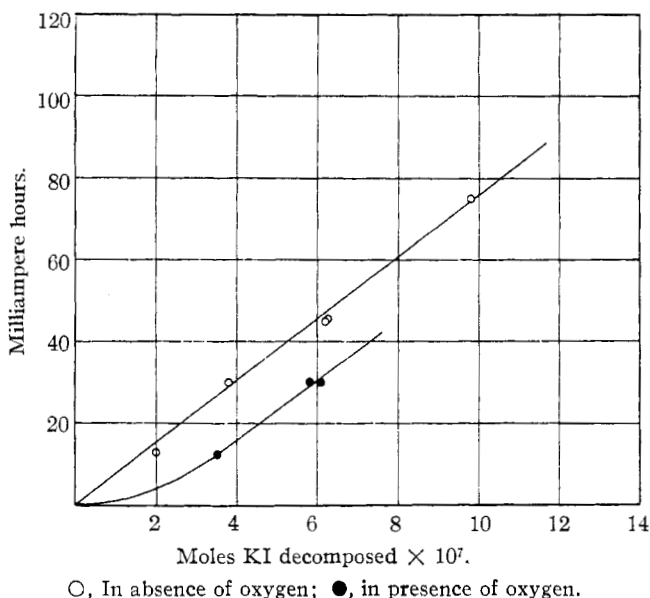


Fig. 1.

In the presence of excess oxygen, however, there is a possibility of the formation and subsequent decomposition of hydrogen peroxide suggested by Glocker, and consequent freeing of iodine. This effect might either supplant or merely add to the reaction discussed above; in either case more iodine would be freed, and the relation between dosage and chemical change might not be linear. This conclusion is consistent with the experimental data.

The same reasoning shows that the decomposition of potassium nitrate is independent in any case of the hydrogen peroxide formation. The reaction occurring is  $\text{KNO}_3 = \text{KNO}_2 + \frac{1}{2}\text{O}_2$ . This is consistent with the

fact that hydrogen peroxide does not affect a solution of potassium nitrate but oxidizes a solution of potassium iodide.

Thus it is concluded that the mechanism of the formation and subsequent decomposition of hydrogen peroxide is not essential for oxidation in aqueous solutions. In certain special cases, however, it may play a contributory part in the total effect.

In connection with the above results, tests were made for the presence of ozone and hydrogen peroxide. A stream of oxygen saturated with water vapor was allowed to flow past a thin glass window which was exposed to radiation. The gas was then passed into an absorption tube containing potassium iodide solution. No trace of free iodine was found after an exposure of fifteen hours, during which time 12 liters of oxygen passed the window, thus indicating that the formation of ozone, unless immediately decomposed, occurred to a negligible extent.

In order to test for hydrogen peroxide, a tube of distilled water was exposed to radiation for nine hours and opened into a solution of potassium iodide. No free iodine was detected. Glocker reports the detection of a small amount of hydrogen peroxide under similar circumstances. Inasmuch as radiation has been conclusively shown to cause the decomposition of hydrogen peroxide, it is probable that a small amount may have formed and decomposed before detection.

### Experiments with Simultaneous Irradiation by Ultraviolet Light and X-Rays

Some recent evidence has been obtained in this Laboratory that the physiological effects of x-rays, for example, on fungi are accentuated by previous or simultaneous ultraviolet irradiation; in other words, the effects of the two kinds of rays are not additive. It was then thought advisable to test this observation with inorganic substances.

Two similar quartz weighing bottles containing 12 cc., each filled with 0.01 *M* potassium iodate are arranged so that the light from a mercury arc lamp is evenly distributed between them. One is in the path of x-rays, from which the other is shielded by a lead screen. The temperature coefficient of the reaction is low, but the temperatures are maintained as nearly equal as possible by cooling with a stream of water or of air from two equal openings in the same nozzle. Inasmuch as there is no procedure suitable for directly determining such small amounts of iodine and potassium iodide in the presence of potassium iodate, the following method was adopted: 10 cc. of the reaction mixture was shaken in a separatory funnel with chloroform. The chloroform layer was drawn off and the residue weakly acidified with 0.4 cc. of *N* sulfuric acid. Under these conditions the potassium iodide and potassium iodate react to give iodine, which is extracted with chloroform. The extracts are titrated with 0.001

*N* sodium thiosulfate. In a run of three and one-half hours at 70 k. v. and 5 m. a., the following results were obtained

	U. v.	U. v. + x-rays	x-rays
Cc. of 0.001 <i>N</i> thiosulfate used I	0.20 cc.	0.13 cc.	....
KI	0.10 cc.	0.20 cc.	....
	0.30 cc.	0.33 cc.	0.03 cc.
Total	0.30 cc.	0.33 cc.	0.03 cc.

In two other experiments, where the difference was measured qualitatively by the depth of color in the chloroform layer, the potassium iodide was found to be appreciably greater in the tube subjected to x-rays, while the iodine formed in the two cases seemed to be about the same with a little more perhaps in the ultraviolet alone. Apparently the effects of ultraviolet light and x-rays in this case are, within experimental error, additive. The mechanism of this complicated decomposition as shown by the distribution between iodine and potassium iodide is evidently affected. The additive effect has been further verified more directly in the photolysis of potassium nitrate.

#### Energy Relations in the Photolysis of Potassium Nitrate by X-Rays

A study has been made of the energy relationships involved in the photolysis of potassium nitrate by x-rays. This reaction has been the subject of much study in connection with the photochemical action of ultraviolet light. The unfiltered radiation from a tungsten target Coolidge tube, operating at 105 k. v. as measured by a sphere gap and 3 m. a., was used in this work. The effective wave length, measured by the Duane method, which involves the determination of the thickness of aluminum which has the same absorbing power as 1 mm. of copper, was found to be 0.236 Å.<sup>8</sup> The intensity and dosage in "r" units<sup>9</sup> of the radiation were measured by a small air wall ionization chamber constructed of Acheson graphite which analyzed as containing 0.2% impurity, and an electrode of aluminum which contained 0.3% iron. The walls of the chamber were 1 mm. thick and the volume 0.999 cc. The saturation current was measured by a Lindemann electrometer calibrated with a standard cell. The solutions used were of 0.01 *M* potassium nitrate contained in pyrex glass bulbs which were blown with thin-walled flat sides. Intensity measurements were made of the incident radiation and of the radiation which had passed through the solution. From measurements of the total area exposed the total amount of energy absorbed could be computed. The solutions

<sup>8</sup> Clark, "Applied X-Rays," McGraw-Hill Book Co., New York, 1927, p. 25.

<sup>9</sup> The international "r" unit adopted by the International Congress of Radiology at Stockholm in 1928 is the quantity of x-radiation which, when the secondary electrons are fully utilized and the wall effect of the chamber is avoided, produces in 1 cc. of atmospheric air at 0° and 76 cm. of mercury pressure, such a degree of conductivity that one electrostatic unit of charge is measured at saturation current.



were analyzed for nitrite by the Warburg method as modified by Villars,<sup>10</sup> using weight burets and 0.001 *N* thiosulfate.

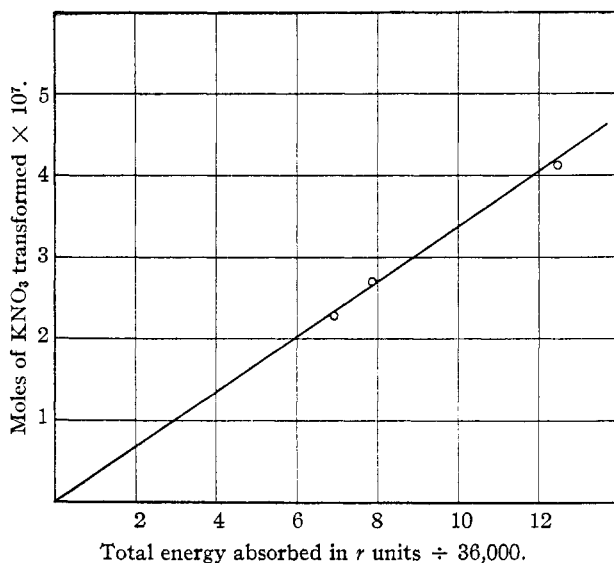


Fig. 2.

The results of three entirely independent experiments illustrated in Fig. 2 are as follows:

Expt.	Exposed area, cm. <sup>2</sup>	Thickness of layer, cm.	Weight of 0.001 <i>N</i> thio, g.	Incident energy per cm. <sup>2</sup> per sec., <i>r</i>	Energy absorbed per cm. <sup>2</sup> per sec., <i>r</i>
1	15.48	1.62	0.4117	2.56	0.80
2	15.90	1.04	.2702	2.32	.490
3	12.91	1.12	.2291	2.40	.535

Total energy absorbed (10 hrs.)	Molecules reacting per <i>r</i> unit	Molecules per ion pair ( <i>M/N</i> )	Energy cal./mole
445,680 <i>r</i>	$5.58 \times 10^{11}$	0.2-0.3	$1.31 \times 10^7$
280,476 <i>r</i>	$5.83 \times 10^{11}$	0.2-0.3	$1.25 \times 10^7$
248,400 <i>r</i>	$5.58 \times 10^{11}$	0.2-0.3	$1.31 \times 10^7$

Fairbrother makes the assumption that a given amount of radiation will produce approximately the same number of ion pairs in a dilute aqueous solution as are produced in the same weight of air, inasmuch as the atomic numbers of air and water are not very different. To allow for relative densities of air and dilute solution, a factor of about 1000 is involved. If this assumption is adopted, the number of molecules of potassium nitrate which react for each ion pair may be calculated

<sup>10</sup> Villars, *THIS JOURNAL*, 49, 326-337 (1927).

$\frac{\text{total energy}}{\text{charge on electron}} = \text{no. ion pairs per cc. in air} = \frac{10^{10}}{4.774} = 2.1 \times 10^9 \text{ ion pairs per cc. in air, or approximately } 2 \times 10^{12} \text{ ion pairs per cc. in the solution;}$

$$\frac{\text{no. molecules reacting}}{\text{no. ion pairs}} = \text{molecules per ion pair}$$

Using the data given above, the values for the latter are between 0.2 and 0.3 for this endothermic decomposition of potassium nitrate. The number of molecules per ion pair may be calculated independently from the energy in calories per mole and the work required to form one ion pair (35 volts):  $(1.313 \times 10^7 \text{ cal./mole KNO}_3) / (23,000 \times 35 \text{ cal./mole ion pairs})$ , or approximately 0.1 molecule of potassium nitrate per ion pair. This is in satisfactory agreement with the value calculated above, considering experimental difficulty, and with the order of magnitude to be expected thermodynamically.

In order to express results in terms of absolute energy, the absorption coefficients and the fraction of the absorbed energy which is converted into the kinetic energy of electrons and thence into the work of formation of ions must be known. The absorption coefficient, 0.228, as calculated from the above data agrees very closely with the value for absorption of the same wave length in water interpolated from a series of values given by Glocker.<sup>5</sup> The fraction of the total absorbed energy converted into work of formation of ions is the ratio of the values of the absorption coefficients for the energy given to recoil and photoelectrons to that of the total absorption coefficient. Using values recorded by Glocker, this fraction for the effective wave length used is 0.263.

The absorbed energy as measured in  $r$  units may be converted into ergs by the use of the formula proposed by Rump<sup>11</sup> and Kulenkampff's<sup>12</sup> experimental value of 35 volts as the work required to form one ion pair in air

$$\frac{E}{i} = \frac{\epsilon}{0.36} \left( \frac{\rho}{\tau + \sigma_v} \right)$$

where  $E/i = 1944 \text{ ergs}/r \text{ unit}$ ,  $\rho = \text{density}$ ,  $\epsilon = 35 \text{ volts}$  and  $\tau + \sigma_v = \text{absorption coefficient attributed to recoil and photoelectrons}$ .

Thus the total energy absorbed in Expt. 1 is  $445,680 \times 1944 \text{ ergs}$ , the fraction 0.263 of which is transformed into work of ionization. At the same time  $4.117 \times 10^{-7} \text{ moles}$  of potassium nitrate are transformed. Thus the energy rate is  $1.313 \times 10^7 \text{ cal./mole}$  of reactant.

The heat of decomposition of potassium nitrate calculated from band spectra of oxygen and thermochemical data<sup>13</sup> is  $1.03 \times 10^5 \text{ cal./mole}$ . Thus it seems evident that not more than 0.8% of the energy absorbed and utilized in formation of ions in the solution appears as chemical dissociation of the molecule of potassium nitrate.

<sup>11</sup> Rump, *Z. Physik*, **43**, 254 (1927).

<sup>12</sup> Kulenkampff, *Ann. Physik*, **79**, 97 (1926).

<sup>13</sup> Villars, unpublished material.

### X-Rays and Colloidal Lead

Since the discovery by Blair-Bell in England that in the treatment of cancer injection of colloidal lead followed by irradiation with x-rays materially increases the therapeutic benefits beyond those from radiation alone, there has been a great interest in the mechanism involved. There are two possibilities: that the finely divided lead produces secondary x-rays *in situ* in the tissues, or that the lead has a specific chemical effect in the tissues entirely apart from any interaction between the colloid and x-rays. In an effort to throw some light upon the mechanism, several experiments have been undertaken with colloidal lead and simple inorganic systems instead of the complex biological tissues.

**Preparation of Colloidal Lead.**—Solutions of colloidal lead were prepared in various dispersion media by the Bredig arc method, using pure lead electrodes of 6 mm. diameter held in an adjustable spark gap device. The beaker in which the colloid was prepared was surrounded by an ice-bath at all times. Some preparations were carried out in a nitrogen atmosphere. Much of the lead used was prepared by the following procedure. An arc was maintained for 10 minutes in 300 cc. of water redistilled from alkaline permanganate, and having a *PH* of 6.6 as measured by Pierre and Fudge's method. The product was centrifuged at 1200 r.p.m. for twenty-five minutes and 1600 r.p.m. for five minutes, siphoned off into containers and covered with a layer of paraffin. In some cases 0.1 cc. of 1% acetic acid was added to 30 cc. of colloidal lead before sealing.

The colloidal lead is black in thick layers and brown in thin layers or at high concentrations. It is stable for months when protected from the air but decomposes rapidly when exposed to air to form a white suspension determined by Telkes<sup>14</sup> as lead carbonate. It is much more stable in a nitrogen atmosphere but decomposition is not entirely prevented. Boiling does not affect the stability. Colloidal lead is coagulated by electrolytes and is a rather vigorous reducing agent. When it is placed in a U-tube fitted with electrodes the boundaries may be seen to move toward the cathode, indicating that the particles are positively charged.

TABLE II  
PREPARATION OF COLLOIDAL LEAD

	Dispersion medium	Time, min.	Arc amps.	Volts	Centrifuge		Pb per 100 g. of soln.	Remarks
					Min.	R.p.m.		
1	Redist. H <sub>2</sub> O <sup>a</sup>	10	2.5	40	5	840	0.04451	..
2	Redist. H <sub>2</sub> O	10	2.6	40	5	1200	.04451	..
3	Redist. H <sub>2</sub> O	15	2.8	40	20 10	1200	.05583	..
						1800	.05470	b
4	Redist. H <sub>2</sub> O	12	2.8	30-40	20 5	1600	....	c
						1800	....	c
5	95% Alcohol	5	2.8	35	10 10	1200	....	d
						600	....	d
6	10% Sucrose	10	2.8	35	20	1200	.05015	e

<sup>a</sup> Plus one drop of 0.1 *N* sodium hydroxide (*PH* 7). <sup>b</sup> Some further settling out at higher rate of centrifuging. <sup>c</sup> 0.1-0.2 cc. of 1% acetic acid added to tubes before sealing. <sup>d</sup> Coagulated. Partially settled. Some remained as colloid for over a week. <sup>e</sup> Less stable on standing than water solution.

<sup>14</sup> Telkes, *THIS JOURNAL*, 49, 1382 (1927).

Table II lists the results obtained in several preparations.

The method used by Telkes for analysis was followed with slight modifications. A 25-cc. sample of colloidal lead was dissolved in 0.8 cc. of 10% acetic acid. Standard potassium dichromate was added in excess and the precipitate allowed to settle. The precipitate was then filtered off, and to the filtrate and washings were added 5 cc. of concd. hydrochloric acid and 5 cc. of 10% potassium iodide. The iodine freed was titrated after three minutes with standard thiosulfate using starch indicator.

**Effect of X-Rays on the Coagulation of Colloidal Lead.**—According to Crowther and Fairbrother, positive colloids are coagulated by exposure to x-rays and consequently this effect should be noted in the case of colloidal lead. A series of experiments seemed to show that the lead was not coagulated but even stabilized to a slight extent.

1. Ten cc. of colloidal lead was placed in each of two thin pyrex test-tubes and covered with a paraffin seal. One was exposed for thirty minutes at a distance of ten inches from the target of a tungsten target tube running at a voltage of 60,000 and a current of 4 to 5 amperes while the other (unexposed) was maintained at nearly the same temperature; 0.6 cc. of 2.7% calcium chloride was added to each and the tubes were viewed against a brightly illuminated background. Eight minutes elapsed before coagulation was visible in the unexposed, eleven minutes for the exposed.

2. The experiment was repeated using a 145-minute exposure at a voltage of 70,000; 0.4 cc. of 0.5% sodium chloride was added to coagulate and forty-four minutes were necessary to obtain visible coagulation of the unexposed, while fifty-three minutes were required for the exposed. This result was duplicated.

3. Two tubes of lead which had been prepared for over a month were placed in the x-ray housing, five inches from the target, one protected by a lead shield, and exposed for ten and one-half hours. A slight amount of decomposition was evident in both; 0.5 cc. of sodium chloride was added to each. In two minutes both had coagulated but the liquid in the case of the unexposed was clear, showing complete coagulation, while the other had the brown color of dilute colloidal lead, evidencing incomplete coagulation lasting for over an hour.

4. The action of rays from a molybdenum target tube operating at 30,000 volts had no apparent coagulatory effect on colloidal lead in a pyrex glass bulb 0.0035 mm. in thickness.

**Secondary Radiation from Colloidal Lead.**—A very thin walled pyrex tube 7 mm. in diameter and 10 mm. in length was adjusted so that a beam of x-rays from a pinhole would pass down the length without hitting the walls of the tube. Around this a piece of film was placed in a cylindrical holder of radius 2 cm. A blank taken with a ten-minute exposure of the empty tube showed no effect upon the film. The film was completely blackened in a ten-minute exposure when the tube was filled with water. With the tube filled with colloidal lead, the blackening decreased with increase in distance from the point where the beam entered the column of lead and increased with time of exposure. It is evident that the intensity of secondary rays produced from the lead when measured at a given distance from the primary beam is very much less than that for secondary rays from water under identical conditions.

**Effect of Colloidal Lead upon a Chemical Reaction.**—The inversion of sugar was chosen for investigation because the reaction in neutral or alkaline solution has been found to be very slightly accelerated by x-rays.

A series of experiments shows that the reaction is not appreciably affected by the presence of colloidal lead during the exposure to x-rays.

1. A 5% solution of sugar with specific rotation at 20° of 66.5 was prepared. Tests showed that the rotation was not affected by several days' standing or prolonged heating at 30°. Then 25 cc. of this solution with 2 cc. of a 0.05% solution of colloidal lead was sealed in a bulb and exposed to x-rays. A similar bulb was protected from the rays. At the end of a six-hour exposure at 60,000 volts and 2 to 5 m. a. the lead was dissolved by 0.1 cc. of *N* acetic acid and the rotation measured. The two readings checked exactly.

2. A solution of colloidal lead in sugar solution was made by arcing for five minutes in a 5% sugar solution and centrifuging for twenty minutes at 1200 r.p.m. After a four-hour exposure at 70,000 v. and 4 m. a. the saccharimeter reading of 38.3 was found to be identical for the solution containing colloidal lead and the original solution similarly exposed to x-rays.

3. Colloidal lead was prepared in a 5% sugar solution and a similar experiment carried out using an irradiation of seventeen and one-half hours. The following data were obtained.

Solution	Sacch. reading, 20°	<i>PH</i>
Original sugar solution	19.1	6.8
Sugar solution exposed to x-rays	19.07	6.8
Sugar soln. contg. coll. lead, 0.05 g. per 100 g. of soln.	19.15	
Sugar soln. contg. coll. lead exposed to x-rays	19.13	7.8
Sugar soln. contg. $\text{Pb}(\text{NO}_3)_2$ exposed to x-rays	18.85	5.6

Inasmuch as acetic acid had to be added to the lead in order to dissolve it, *PH* measurements could not be made. The value given was for an undissolved portion which had been exposed to the air and had formed the white cloudy lead carbonate, which did not interfere with the colorimetric measurement but showed nothing about *PH* of colloidal lead except that it was not acid.

It may be concluded that colloidal lead has no effect upon the inversion of sucrose by x-rays; a considerable effect is observed in the presence of lead nitrate, but the change in *PH* alone may account for this. Hence upon the basis of these experiments the mechanism of the action of colloidal lead in the tissues seems to be the specific chemical effect, rather than the production of secondary rays. This agrees with the recent observation that colloidal gold which should produce secondary rays as easily as lead, has no beneficial effects whatever in the Blair-Bell technique.

### The Flocculation of Colloidal Clays

The action of x-rays in flocculating colloids is an established fact. Clay solutions are usually highly colloidal. It was the purpose of this experiment to find out the action of x-rays on the clay slips. It was taken for granted that flocculation bears a direct relationship with the viscosity of the slip, that is, flocculation increases with viscosity, other things being equal.

Advantage was taken of this relationship, therefore, by first taking a measurement of the viscosity of the slip before raying, and then after

raying for a certain time. The change of viscosity is a direct measure of amount of flocculation.

The viscosity was measured by means of a viscosimeter. A certain volume of the solution was allowed to drain off continuously from a large capillary, and the time recorded accurately by means of a stop watch. The following formula expresses the relative viscosity of a slip

$$V = \frac{t_s \cdot S_s}{t_w \cdot s_w}$$

where  $V$  is relative viscosity of the slip,  $t_s$  is the time required for 100 cc. of the clay slip to flow through the viscosimeter (in seconds),  $S_s$  is the specific gravity of the clay slip,  $t_w$  is the time required for 100 cc. of distilled water at the same temperature of the slip to flow through the viscosimeter (in seconds) and  $s_w$  is the specific gravity of water at that temperature.

The clay slips were enclosed in 1-liter glass vessels tightly closed and exposed to radiation from a molybdenum target x-ray tube at 30,000 volts for 1200 milliamper hours.

The data and calculations are as follows

1. Florida Kaolin

$t_s$  = time for 100 cc. of slip before raying to flow through the viscosimeter = 21 sec.

$t_w$  = time for 100 cc. of water to flow through the viscosimeter = 12.0 sec.

$t'_s$  = time for 100 cc. of slip after raying to flow through the viscosimeter = 21 sec.

$S_s$  = 1.210 = specific gravity of the slip.

$s_w$  = 1.0 = density of water.

Relative viscosity before raying =  $\frac{21 \times 1.210}{12 \times 1.00} = 2.12$ , the same as that after raying.

Hence x-rays have no effect of flocculation on Florida kaolin, which is a very pure kaolin.

2. Anna, Illinois, Kaolin.

$t_s$  = 25 sec. before raying.

$t'_s$  = 29 sec. after raying.

$S_s$  = 1.197

$t_w$  = 12 sec.  $s_w$  = 1.0

$V$  before raying =  $(25 \times 1.197)/(12 \times 1) = 2.49$

$V$  after raying =  $(29 \times 1.197)/(12 \times 1) = 2.90$

Increase in relative viscosity due to raying, 16.5%.

3. Tennessee Ball Clay No. 5

$t_s$  = 22.5 sec. before raying

$t'_s$  = 25.5 sec. after raying

$S_s$  = 1.200

$V$  before raying =  $(22.5 \times 1.20)/(12 \times 1) = 2.25$

$V$  after raying =  $(25.5 \times 1.20)/(12 \times 1) = 2.55$

Increase in relative viscosity due to raying, 11.8%.

An analysis of the latter two clays shows that they are impure kaolins containing some proteins and other organic substances; the increase in

relative viscosity due to raying is a relative measure of the amount of protein substance present, since the pure Florida kaolin is entirely unaffected. Therefore, the protein is most sensitive to coagulation and affects the slips markedly even though present in very small amounts.

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### Summary

1. Several chemical systems which are known to undergo photochemical change in ultraviolet light are investigated with x-rays, in most cases of an effective wave length of  $0.24 \text{ \AA}$ . Most of the changes, if any, are very small.

2. The most sensitive reactions found besides oxidation of solutions of ferrous to ferric salts are a series of aldehyde-ketone condensations, investigated photochemically for the first time. Aldehyde-aldehyde condensations are much less affected by x-radiation.

3. The energy relations involved in the photolysis of potassium nitrate by x-rays are quantitatively determined, including an accurate measurement of intensity and dosage in "r" units with a 1 cc. air-wall ionization chamber. There are  $5.58 \times 10^{11}$  molecules reacting per r unit or approximately 0.2 molecule per ion pair. The energy in calories per mole is  $1.31 \times 10^7$ . Thus less than 0.8% of the energy absorbed and utilized in the formation of ions in solution appears as chemical dissociation of the potassium nitrate molecule.

4. Simultaneous irradiation of potassium iodate and potassium nitrate solutions with x-rays and ultraviolet light produces additive chemical effects in contrast with non-additive biological effects on fungi, etc.

5. A thorough test is made in potassium iodide and potassium nitrate solutions of the theory that chemical effects are secondary and due to the formation of hydrogen peroxide.

6. Colloidal lead used in the Blair-Bell technique for cancer therapy is studied from the standpoints of preparation, stability, coagulation by x-rays, production of secondary x-rays and catalytic effect in reactions subjected to irradiation. The specific chemical effect rather than the action of producing secondary x-rays *in situ* in the tissues is indicated.

7. The coagulation by x-rays as determined by viscosity changes of colloidal clay slips is found to be a function of the amount of organic protein materials present.

URBANA, ILLINOIS