

ment of the hydroxyl group toward the center of the molecule but in these ketones, the carbonyl group tends to decrease the solubility as it is moved toward the center (nos. 3 and 4; 6 and 9; 8 and 10). The effect of the carbonyl position is especially noticeable in the case of no. 7, resulting in an unexpected decrease in the solubility (nos. 8, 6, 5 and 7). These ketones all become less soluble with increasing temperature.

Summary

Aqueous solubilities of twelve aliphatic ketones have been determined for 20, 25 and 30°. Low molecular weights and low temperatures result in large solubilities. The most compact isomers tend to be most soluble but movement of the carbonyl group toward the center of the molecule tends to reduce the aqueous solubility.

GREENSBORO, N. C.

RECEIVED MAY 10, 1940

[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY, THE RICE INSTITUTE]

The Electrolyte Coagulation Process: the Influence of Dilution of Sol on the Adsorption of Precipitating Ions

BY HARRY B. WEISER AND W. O. MILLIGAN

The concentration of electrolytes required to coagulate hydrophobic sols varies with the concentration of sol, a phenomenon first observed by Mukopadhyaya.¹ Burton and Bishop² formulated the rule that, in general, the precipitation value of univalent precipitating ions increases with dilution of sol; that of bivalent ions is almost constant and independent of the sol concentration; and that of trivalent ions decreases with the sol concentration. Weiser and Nicholas³ pointed out that Burton and Bishop's rule is not generally applicable since with many sols, especially those of the hydrous oxides, the precipitation value of electrolytes decreases with dilution of sol irrespective of the valence of the precipitating ion. Sorum⁴ showed, however, that certain hydrous oxide sols which do not follow Burton and Bishop's rule when relatively impure will obey the rule after sufficient purification by dialysis, but no explanation is offered for this behavior.

Because of the limitations of rules of electrolyte coagulation which attempt to formulate the conditions for reducing the potential on the dispersed particles to a critical value, Ostwald⁵ introduced the principle that the dispersion medium rather than the colloidal particles should be in a corresponding (in the simplest case identical) physical-chemical state for coagulation to take place. It is argued that coagulation should take place at the

same activity coefficient of the precipitating ion (f^+ for negative sols and f^- for positive sols) irrespective of the salt employed. The activity coefficient of a single cation, for example, is given in accord with the Debye-Hückel theory by a relation of the form $-\log f^+ = 0.5 (z^+)^2 \sqrt{u/n^+}$, in which z is the valence of the cation, n^+ the number of cations in the molecule and u is the ionic strength which is given by the expression $u = 0.5 [m^+(z^+)^2 + m^-(z^-)^2]$, where m^+ and m^- are the molarities of the cation and anion, and z^+ and z^- are the valences of the respective ions in the coagulating electrolyte.

Ostwald's simple formulation, f^+ (or f^-) = constant, is necessarily limited in its applicability.⁶ In the first place, the precipitation values of electrolytes vary in different ways with dilution of sol so that in general the activity coefficient of the precipitating ion at the coagulation value cannot be constant over any wide range of concentration. In the second place, if Ostwald is right that the dispersion medium should be in the same physical-chemical state for coagulation to take place, then the activity coefficients of the precipitating ions in equilibrium with the particles should be compared rather than the activity coefficients calculated on the basis of the total amount added to effect coagulation. If such a comparison is made there is no reason to believe that the critical activity coefficients will approach a constant value for ions of varying valence since only a small percentage of univalent ions is adsorbed at their precipitation value whereas a large percentage of most multi-

(1) Mukopadhyaya, *THIS JOURNAL*, **37**, 2024 (1915); Kruyt and van der Spek, *Kolloid. Z.*, **25**, 3 (1919).

(2) Burton and Bishop, *J. Phys. Chem.*, **24**, 701 (1920); Burton and MacInnes, *ibid.*, **25**, 517 (1921).

(3) Weiser and Nicholas, *ibid.*, **25**, 742 (1921).

(4) Judd and Sorum, *THIS JOURNAL*, **52**, 2598 (1930); Fisher and Sorum, *J. Phys. Chem.*, **39**, 283 (1935); **44**, 62 (1940).

(5) For a survey with references see *ibid.*, **42**, 981 (1938).

(6) Cf. Weiser, "Inorganic Colloid Chemistry," Vol. III, John Wiley and Sons, New York, N. Y., 1938, pp. 190 *et seq.*

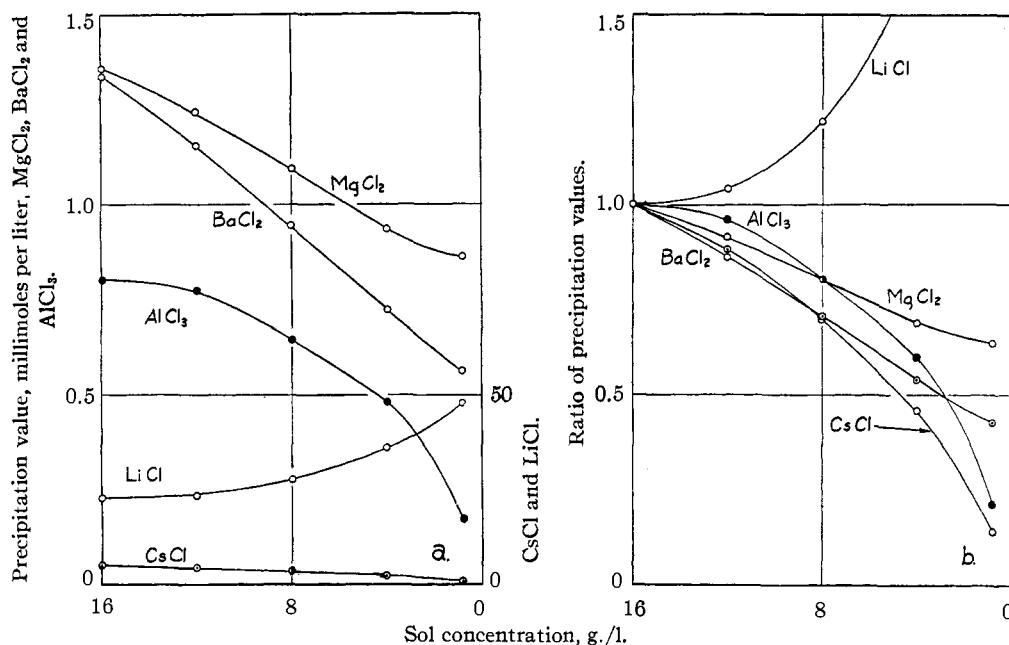


Fig. 1.—The influence of concentration of copper ferrocyanide sol on its stability toward electrolytes.

valent ions is adsorbed at their precipitation value.

In this paper consideration will be given to the limitations of Burton and Bishop's rule and Ostwald's rule, and to the effect of dilution on the stability of sols as disclosed by a study of the adsorption of precipitating ions during the coagulation process.

Experiments with Copper Ferrocyanide Sols.

Preparation.—Relatively pure negatively charged copper ferrocyanide sol was prepared by the method of Weiser and Milligan.⁷ This consists essentially in thorough washing of copper ferrocyanide gel by the aid of the centrifuge followed by peptization in 0.005 *N* potassium ferrocyanide. By dilution of the original sol, sols containing 20, 15, 10, 5, and 1 g. per liter were made up and were allowed to stand for two years before use. Although this period of aging is excessive, considerable time should be allowed for equilibrium to be established between the micelles and the intermicellar liquid.

Precipitation.—The precipitation value of an electrolyte for a sol is taken as that quantity of electrolyte which is just sufficient to cause complete coagulation of the sol within a given time. To 10 ml. of sol was added all at once varying amounts of electrolyte diluted to 12.5 ml. By a systematic procedure of trial and error, that quantity of electrolyte was found which would just cause complete coagulation in twenty-four hours. The precipitation values of several electrolytes and the activity coefficients of the corresponding cations on copper ferrocyanide sols, are given in Table I. The influence of the sol concentration on the precipitation value of the several electrolytes is represented graphically in Fig. 1a and the ratio of each

precipitation value for a given electrolyte to that of the strongest sol is plotted in Fig. 1b.

TABLE I
PRECIPITATION OF $\text{Cu}_2\text{Fe}(\text{CN})_6$ SOL

Concn. of sol after dilution, g./l.	—Precipitation values ρ in millimoles per liter—					
	BaCl ₂		MgCl ₂		AlCl ₃	
	ρ	$f_{\text{Ba}^{++}}$	ρ	$f_{\text{Mg}^{++}}$	ρ	$f_{\text{Al}^{+++}}$
16.0	1.336	0.75	1.360	0.74	0.800	0.49
12.0	1.152	.76	1.240	.756	.733	.50
8.0	0.944	.78	1.092	.77	.640	.53
4.0	.720	.81	0.936	.78	.480	.57
0.8	.560	.83	.864	.79	.171	.72
	CsCl		KCl		LiCl	
	ρ	f_{Cs^+}	ρ	f_{K^+}	ρ	f_{Li^+}
16.0	8.00	0.90	15.0	0.87	36.0	0.80
12.0	7.04	.91	15.0	.87	37.5	.80
8.0	5.60	.92	14.4	.87	44.0	.79
4.0	3.68	.93	13.8	.87	58.0	.76
0.8	1.12	.96	13.8	.87	78.0	.73

Even a superficial examination of the curves reveals a marked divergence from Burton and Bishop's rule. Although the precipitation value of univalent lithium ion increases markedly with dilution, that of univalent cesium ion falls off greatly with dilution. Indeed the rate of decrease in precipitation value with dilution is greater for univalent cesium than for trivalent aluminum. Moreover, the precipitation value of the divalent ions falls off with dilution of sol as rapidly as that of aluminum ion.

Adsorption of Precipitating Ions.—The adsorption of certain precipitating ions at the precipitation value was determined by a procedure which we have employed frequently in the past. To 50 ml. of sol was added all at once the precipitation concentration of electrolyte in a total volume of 62.5 ml. The precipitations were carried out in 130-ml. vessels used in an angle centrifuge. After

(7) Weiser and Milligan, *J. Phys. Chem.*, **40**, 1071 (1936).

TABLE II

Concn. of sol, g./l.	Sol	ADSORPTION OF Ba ⁺⁺ AND Al ⁺⁺⁺ DURING PRECIPITATION OF Cu ₂ Fe(CN) ₆ SOL					Adsorption of Ba ⁺⁺	
		Ml. mixed (Total volume 62.5 ml.) N/50 BaCl ₂ ^a		H ₂ O	1	2	Average	Mg.
20	50	8.35	4.15	2.7	2.4	2.55	9.67	9.67
15	50	7.20	5.30	3.0	2.9	2.95	7.80	10.40
10	50	5.90	6.60	2.8	2.6	2.70	6.11	12.22
5	50	4.50	8.00	2.5	2.8	2.65	4.22	16.88
1	50	3.50	9.00	4.4	4.5	4.45	1.53	30.60

Concn. of sol, g./l.	Sol	N/50 AlCl ₃ ^a		Mg. Al ₂ O ₃ in 50 ml. of supernatant solution		Adsorption of Al ⁺⁺⁺	
						Mg.	Mg./g.
20	50	7.50	5.00	0.07		1.33	1.33
15	50	7.25	5.25	.07		1.30	1.73
10	50	6.00	6.50	.09		1.06	2.12
5	50	4.50	8.00	.12		0.80	3.20
1	50	1.60	10.90	.10		.28	5.60

^a Precipitation concentration.

standing for twenty-four hours, the solutions were centrifuged for two hours, after which 50-ml. samples of the supernatant solutions were analyzed. The results of the observation of adsorption of barium ion and aluminum ion are given in Table II. Barium was determined as the sulfate and the minute amount of aluminum at the equilibrium concentration was estimated colorimetrically with aluminon. In both instances the adsorption per gram of copper ferrocyanide increases with dilution of sol.

Experiments with Ferric Oxide Sol

Preparation.—Positively charged ferric oxide sol was made by the general directions of Neidle and Barab.⁸ To a ferric chloride solution was added all at once the maximum amount of ammonium hydroxide found by trial to be just short of that which would give a permanent precipitate on agitating for two hours. The resulting sol was dialyzed first in the cold and then at 100° in a cellophane tube dialyzer until the desired state of purity was reached. In the original sol containing 19.15 g. of ferric oxide per liter, the ratio equivalents iron:equivalents chlorine was 48. From this sol, more dilute sols containing 15, 10, 5, and 1 g. ferric oxide per liter were made up. The five preparations were aged on the hot-plate for one week at 75° in flasks fitted with reflux condensers to prevent evaporation.

Precipitation.—The precipitation values of potassium chloride, potassium sulfate, and potassium ferricyanide for the positively charged sols were determined as described for negatively charged copper ferrocyanide sols. In Fig. 2 are plotted (a) the precipitation values and (b) the ratio of precipitation values, against the sol concentration. Again, there is almost nothing to suggest Burton and Bishop's rule. Although the preparations are relatively pure for sols of this type, the precipitation value of the univalent chloride ion is practically independent of the concentration of sol; and the precipitation values of divalent sulfate and trivalent ferricyanide fall off at approximately the same rate with dilution of sol.

Adsorption of Precipitating Ions.—Observations of the adsorption of sulfate and ferricyanide ions are shown in Table III. With this sol the adsorption of the multivalent ions was very strong. The 50-ml. samples of

TABLE III

ADSORPTION OF SO₄⁼ AND Fe(CN)₆⁼ DURING PRECIPITATION OF Fe₂O₃ SOL

Concn. of sol, g./l.	Sol	Ml. mixed (Total volume 62.5 ml.) N/50		BaSO ₄ in supernatant solution	Adsorption of SO ₄ ⁼	
		K ₂ SO ₄ ^a	H ₂ O		Mg.	Mg./g. Fe ₂ O ₃
19.15	50	13.00	0.00	0.0	12.50	13.00
15.0	50	11.50	1.00	.0	11.05	14.73
10.0	50	8.60	3.90	.0	8.26	16.52
5.0	50	4.90	7.60	.0	4.73	18.92
1.0	50	1.10	11.40	.0	1.06	21.20

Concn. of sol, g./l.	Sol	N/80 K ₂ Fe(CN) ₆ ^a		Fe(CN) ₆ ⁼ in supernatant solution	Adsorption of Fe(CN) ₆ ⁼	
					Mg.	Mg./g.
19.15	50	12.50	0.00	0.0	14.72	15.35
15.0	50	11.25	1.25	.0	13.25	17.66
10.0	50	8.50	4.00	.0	10.00	20.00
5.0	50	5.00	7.50	.0	5.89	23.56
1.0	50	1.05	11.45	.0	1.24	24.80

^a Precipitation concentration.

supernatant solution were evaporated to 5 ml.; those from the sulfate failed to give a test on treating with barium chloride and those from ferricyanide failed to give a Turnbull's blue test with ferrous ammonium sulfate. As with copper ferrocyanide sol, the adsorption of precipitating ions per gram of ferric oxide increases with dilution of sol.

Experiments with Arsenic Trisulfide Sol

Preparation.—The sol was prepared by the action of hydrogen sulfide on a cold saturated solution of arsenic trioxide according to a modification of the nuclear method of Freundlich and Nathansohn.⁹ Excess hydrogen sulfide was removed by washing with hydrogen. After filtering to remove unpeptized sulfide, the sol containing 38.6 g. of arsenic trisulfide per liter was diluted to give sols containing 30, 20, 10, 5, and 1 g. per liter. These preparations stood in the dark for one week before use.

Precipitation.—The precipitation values and ratio of precipitation values against sol concentration for the chlorides of lithium, cesium, barium, and aluminum are given in Fig. 3. In accord with earlier observations, these data approach more nearly what would be expected from

(8) Neidle and Barab, *THIS JOURNAL*, **39**, 79 (1917).

(9) Freundlich and Nathansohn, *Kolloid-Z.*, **28**, 258 (1921).

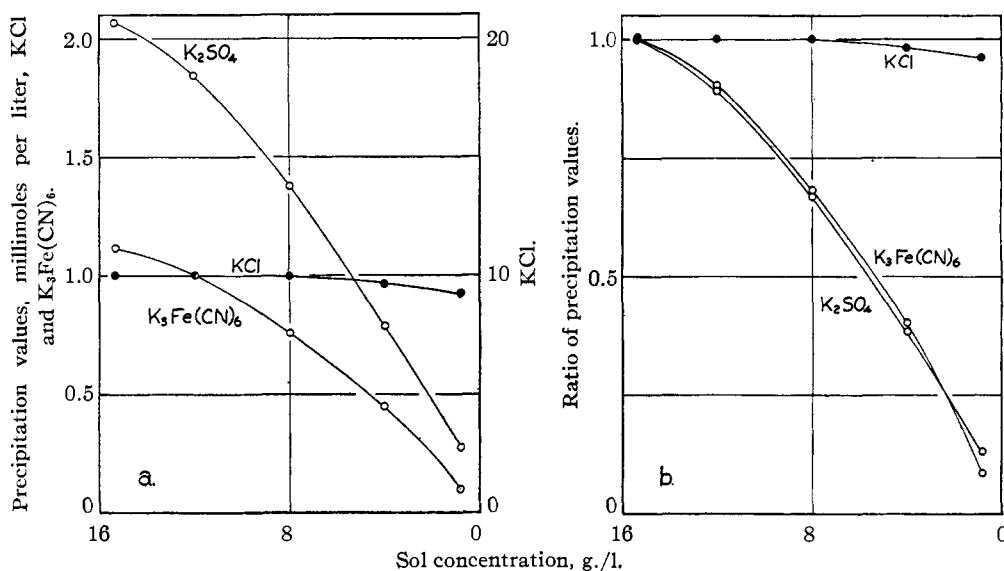


Fig. 2.—The influence of concentration of ferric oxide sol on its stability toward electrolytes.

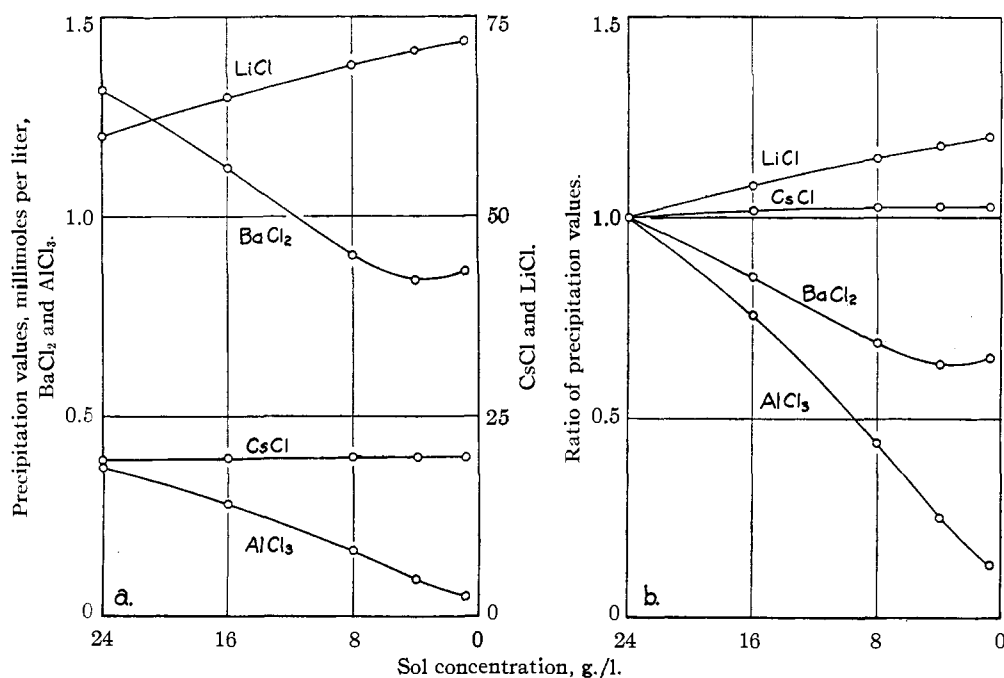


Fig. 3.—The influence of concentration of arsenic trisulfide sol on its stability toward electrolytes.

Burton and Bishop's rule; but even in this case considerable divergence from the rule is apparent. Thus the precipitation value of univalent lithium ion increases with dilution of sol in accord with Burton and Bishop's rule; but that of univalent cesium ion is almost independent of the sol concentration. The distinct falling off in the precipitation values of divalent barium ion on dilution of sol is likewise not in accord with Burton and Bishop's rule.

Attention should be called to the fact that the precipitation value of barium chloride for the most dilute sol is somewhat higher than for the one containing 5 g. of arsenic

trisulfide per liter. At sufficient dilution of sol all the curves will finally bend upward.¹⁰

Adsorption of Barium Ion.—The results of observations of adsorption of barium ion by arsenic trisulfide sols at the respective precipitation values are given in Table IV. Here again the adsorption per unit amount of adsorbent increases with dilution of sol from which the adsorbing gel separates. This is of special significance since at one

(10) Wannow and Hoffmann, *Kolloid-Z.*, **77**, 46 (1936); **80**, 294 (1937).

TABLE IV
ADSORPTION OF Ba^{++} DURING PRECIPITATION OF As_2S_3 SOL

Concn. of sol, g./l.	Ml. mixed (Total volume 62.5 ml.)		Mg. $BaSO_4$ in 50 ml. of supernatant solution				Adsorption of Ba^{++}	
	Sol	$N/50$	H_2O	1	2	Average	Mg.	Mg./g. As_2S_3
30	50	8.25	4.25	5.7	6.2	5.95	6.93	4.62
20	50	6.90	5.60	6.0	6.5	6.25	4.87	4.87
10	50	5.65	6.85	6.8	6.9	6.85	2.70	5.40
5	50	5.25	7.25	7.4	7.6	7.50	1.68	6.72
1	50	5.40	7.10	8.7	8.8	8.75	0.96	19.20

^a Precipitation concentration.

time Freundlich¹¹ believed that equivalent amounts of various precipitating ions are adsorbed at their respective precipitation values for a given sol. Not only does the adsorption of different ions by the same coagulum vary markedly from equivalence, but the above data show that adsorption of the same ion by the same coagulum varies with the concentration of the sol from which it separates.

Discussion

In the coagulation of hydrophobic sols by electrolytes, the mobility or electrokinetic potential of the particles is lowered to a certain critical range by adsorption of ions opposite in sign of charge to that on the particles. Any change in stability on dilution should be accompanied by a change in the adsorption of precipitating ion required to reduce the potential on the particles to the critical range. Figure 4 illustrates the dependence of dilution of sol on the adsorption of cations at their precipitation value for typical negative sols. The increased adsorption on dilution supports the view that dilution stabilizes the

sol toward all precipitating ions. This accords with the observation that *proportionately* more electrolyte is required to precipitate the diluted sols than the more concentrated ones irrespective of the valence of the precipitating ion.

The slope of the precipitation value-sol concentration curve depends upon (a) the adsorbability of the precipitating ion; (b) the stabilizing effect of adsorption of the stabilizing ions which have the same sign of charge as the sol particles³; and (c) the purity of the sol diluted. These factors will be considered in order.

The adsorbability of a precipitating ion depends not only upon the valence, but also on the size, degree of hydration, and ease of deformability of the ion. A rule such as Burton and Bishop's which implies that the slope of the precipitation value-sol concentration curve is a function only of the valence of the precipitating ion, is necessarily limited in its applicability.

The effect of adsorption of the stabilizing ion of a coagulating electrolyte is of particular importance only when the concentration of the counter stabilizing ions is high.^{3,12} Such a condition obtains with uni-univalent electrolytes that have a high precipitation value. This is in part responsible for the observed fact that the precipitation value of such electrolytes either increases with dilution of sol or decreases less with dilution of sol than does the precipitation value of electrolytes which produce coagulation in low concentrations.

The effect of purity of sol on the slope of the precipitation value-sol concentration curves, as observed by Sorum, is in accord with what one would expect. The purer the original sol, the more instable it is toward electrolytes; and up to a certain point, the greater the amount of stabilizing electrolyte in a sol, the more stable it is.¹³ Since dilution increases the stability of sols, one would predict that a sol formed by dilution of a highly pure, relatively instable preparation would be proportionately more stable than a sol formed by dilution of an impure highly stable preparation. In other words, the purer the sol, the less one would expect the precipitation value of electrolytes to fall off with dilution, as Sorum found.

In the light of the several factors that determine the effect of dilution of sol on the precipitation value of electrolytes, it is apparent that only a fortuitous combination of circumstances as re-

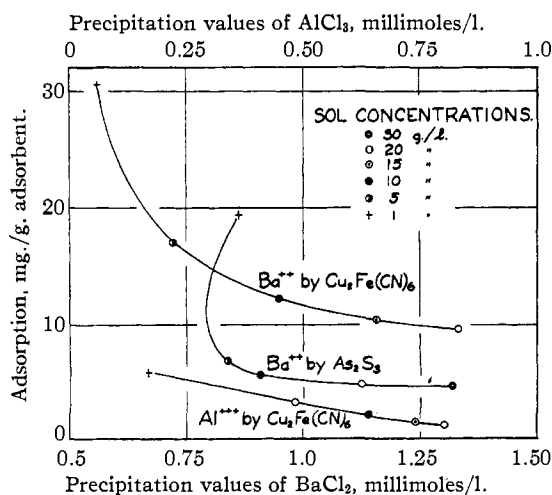


Fig. 4.—Adsorption of cations by negative sols of varying concentrations.

(11) *Kolloid-Z.*, **1**, 321 (1907); **12**, 232 (1913); *Z. physik. Chem.*, **73**, 408 (1910); Gann, *Kolloid-Beihfte*, **8**, 73 (1916); cf., however, Weiser and Middleton, *J. Phys. Chem.*, **24**, 30, 630 (1920); Weiser, *ibid.*, **29**, 955 (1925); Freundlich, Joachimsohn and Ettisch, *Z. physik. Chem.*, **141A**, 249 (1929).

(12) Cf., also, Hauser and Hirshon, *J. Phys. Chem.*, **43**, 1015 (1939).

(13) Weiser, *ibid.*, **30**, 20 (1926).

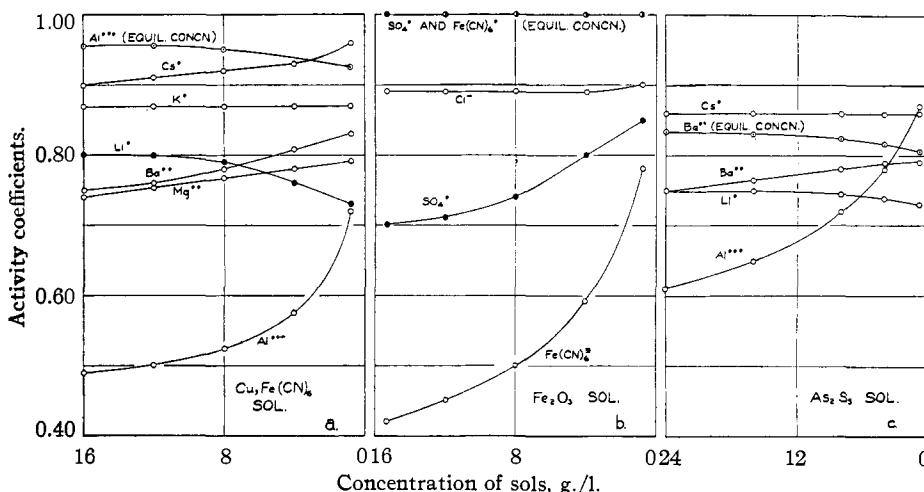


Fig. 5.—Activity coefficients of precipitating ions at their precipitation values for sols of varying concentration.

gards nature of sol, purity of sol, and adsorbability of the precipitating ions of a given valence, can give precipitation value-sol concentration curves that are in accord with Burton and Bishop's rule.

The results of this investigation lead to the following restatement of Burton and Bishop's rule: For a given sol, the *proportionate* increase in stability toward precipitating electrolytes on dilution is in general greater for electrolytes with univalent precipitating ions than for electrolytes with multivalent precipitating ions; and is greater the higher the purity of the original sol.

In Fig. 5 the activity coefficients of various precipitating ions are plotted against the sol concentration for the three sols investigated. It is apparent that Ostwald's rule, $f^+ = \text{constant}$ for negative sols or $f^- = \text{constant}$ for positive sols, does not apply to these data at any concentration of sol. The divergence from a constant value for the activity coefficients of various precipitating ions is greater when they are calculated from the equilibrium molarities at the precipitation value than when they are calculated from the total added molarities. It will be recalled that in the case of ferric oxide sol the equilibrium concentration at the precipitation value of sulfate and ferricyanide ions approaches zero, the corresponding activity coefficients approaching unity (Fig. 5b).

Summary

1. A study has been made (a) of the effect of concentration of sol on the precipitation value of electrolytes for relatively pure sols of copper ferrocyanide, ferric oxide, and arsenic trisulfide and (b) of the adsorption of precipitating ions at

their respective precipitation values for the sols. With each sol marked variations from Burton and Bishop's rule were observed.

2. The adsorption of precipitating ions at their respective precipitation values increases with dilution of sol, indicating that dilution stabilizes the sol toward all precipitating ions. This accords with the observation that *proportionately* more electrolyte is required to precipitate dilute sols than more concentrated ones irrespective of the valence of the precipitating ion.

3. The slope of the precipitation value-sol concentration curve depends upon (a) the adsorbability of the precipitating ions; (b) the stabilizing effect of the adsorption of ions having the same sign of charge as the sol; and (c) the purity of the sol.

4. Since the adsorbability of precipitating ions depends not only on their valence but also on their size, degree of hydration, and ease of deformability, Burton and Bishop's rule which implies that the slope of the precipitation value-sol concentration curve is a function only of the valence of the precipitating ion, is necessarily limited in its applicability.

5. The effect of adsorption of stabilizing ions on the precipitation value is of particular importance with electrolytes that precipitate only in high concentrations, *e. g.*, certain uni-univalent electrolytes. This effect may be responsible in part for the observed fact that the precipitation value of such electrolytes may increase with dilution or decrease less with dilution than that of electrolytes which coagulate in low concentration.

6. The purer the original sol the more instable it is toward electrolytes; and up to a certain point

the more stabilizing electrolyte in a sol the greater its stability. A sol formed by dilution of a pure, relatively instable preparation is proportionately more stable than a sol formed by dilution of an impure highly stable preparation. This explains Sorum's observation that the purer a sol, the less the precipitation values of electrolytes fall off with dilution.

Only a fortuitous combination of circumstances as regards nature of sol, purity of sol, and adsorbability of precipitating ions of a given valence, can give precipitation value-sol concentration curves that are in accord with Burton and Bishop's rule.

7. Burton and Bishop's rule may be restated as follows: For a given sol, the *proportionate* increase

in stability toward precipitating electrolytes on dilution, is in general greater for electrolytes with univalent precipitating ions than for electrolytes with multivalent precipitating ions; and is greater the higher the purity of the original sol.

8. Ostwald's rule that the activity coefficient of various precipitating ions is a constant at their precipitation value, does not apply to the observations herein reported at any concentration of sol. The divergence from a constant value for the activity coefficients of various precipitating ions at their respective precipitation values is greater if they are calculated from the equilibrium molarities after adsorption than from the total added molarities.

HOUSTON, TEXAS

RECEIVED APRIL 29, 1940

[CONTRIBUTION FROM THE CHEMICAL LABORATORY OF THE UNIVERSITY OF CALIFORNIA]

Reactions of High Energy Atoms Produced by Slow Neutron Capture

BY W. F. LIBBY

Introduction

Slow neutron capture by most nuclei (the principal exceptions are Li, B and U) results in the immediate emission of gamma ray quanta with average energy between 3 and 6 million electron volts,^{1,2,3} generally followed by negative or beta radioactivity. (Throughout this report these radioactive atoms will be designated by asterisks, e. g., Mn^{*++} for radioactive Mn⁺⁺ ions.) The momentum of the gamma quantum, $h\nu/c$, is balanced by a recoil of the emitting nucleus of mass M in atomic weight units involving the energy $(h\nu/c)^2/2M$, i. e., $533(E_\gamma)^2/M$ e. v. if E_γ is the gamma energy in MEV. This recoil causes the molecule to explode nearly always. It is these processes that have been investigated in this research by study of the distribution of the resultant radioactivity among the molecules in the system.

There is a possibility that the emission of more than one gamma quantum would lead to partial cancellation of the recoil momenta, reducing the energy of recoil of the nucleus, but the fact that only 8 MEV are available on the average (mass defect of the neutron) and that nearly 2 MEV of this is required for the beta radioactivity, shows that the number of gamma quanta cannot greatly

exceed two. If it did the average energy of the radiation could not be between 3 and 6 MEV. Therefore the cancellation of momenta must be a very improbable occurrence, since the cancellation for two gamma quanta would require that they have identical energies as well as opposite directions. This agrees completely with the experimental results. Since these recoil energies, even in the cases of the heavier elements, considerably exceed chemical bond energies, it is reasonable to expect that in most cases a disruption of the molecule containing the atom absorbing the neutron will result. For example, in the case of Mn, if E_γ is 2, the recoil energy is calculated to be at least 40 electron volts. It is the purpose of this paper to present the results of some experiments on these explosion processes and the following reactions of the very energetic atoms, molecules, free radicals or ions resulting from them. Of course only those particles carrying radioactive atoms actually will be followed. In addition, certain data on isotope exchanges will be presented.

In general the reactions of that fragment of the initial molecule which contains the radioactive atom after the recoil might be of any type involving only the fragments of the recoil and the main molecules in the substance being irradiated. It is certain, however, that no reaction involving

(1) F. Rasetti, *Z. Physik*, **97**, 64 (1935).

(2) R. Fleischmann, *ibid.*, **97**, 242-265 (1935).

(3) S. Kikuchi, K. Fushimi and H. Aoki, *Proc. Phys.-Math. Soc. Japan*, **18**, 188 (1936).