

KINETICS OF THE AUTOXIDATION OF VITAMIN A CATALYSED BY COBALT ION¹

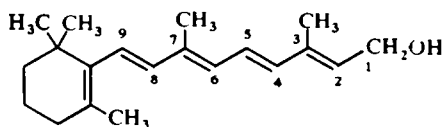
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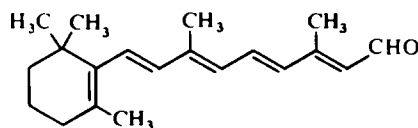
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Abstract—Vitamin A, dissolved in liquid paraffin, is stable below room temperature, but suffers oxidative decomposition at 80°, giving its epoxide as the main product. The rate of decomposition of vitamin A (V_A) at 80° in the presence of oxygen (partial pressure of p) and a small amount of cobaltous stearate (Co) is expressed as: $-d[V_A]/dt = 3.15 \times 10^{-1}[V_A][Co] p^{1.48} + 1.51 \times 10^{-5}[V_A] p^{0.33} + 0.33 \times 10^{-5}[V_A]$, where the last term represents the spontaneous thermal decomposition.

VITAMIN A which is a conjugated primary alcohol (I) is one of the most important vitamins. There have been a number of qualitative investigations on the stability of vitamin A in light, heat, air or other oxidizing agents, but a quantitative study has been neglected. Bolomey² noticed a gradual shift of the UV absorption maxima from 326–328 m μ to 274–275 m μ during the autoxidation of vitamin A in fish liver oil. Troitskič³ reported the formation of epoxide after exposing vitamin A to air for 20–40 days, while Karrer and Hess⁴ observed carbonyl compounds on autoxidation of vitamin A in the presence of PtO₂. Also vitamin A aldehyde (II) is said to be formed on autoxidation of vitamin A in the presence of MnO₂⁵.



Vitamin A (I)



Vitamin A aldehyde (II)

There seems to be no other literature on the metallic ion catalysis, which is observed in general autoxidations.

In the present paper, the kinetics of the autoxidative conversion of vitamin A in the presence of cobalt catalyst and of the product formed are studied to afford some quantitative information on the stability of vitamin A.

RESULTS AND DISCUSSION

The kinetic study on the autoxidation of vitamin A (V_A) was carried out in liquid paraffin at 80° in the presence of cobalt stearate and pure oxygen at *ca* 1 atm. The rate of disappearance of V_A was followed by UV absorption ($E_{324.5}$) at λ_{\max} of 324.5 m μ ,

since V_A has an absorption maximum in a MeOH solution. The rate equation is expressed satisfactorily by Eq 1.

$$-d[V_A]/dt = k_1[V_A] \quad (1)$$

where k_1 is pseudo-first-order rate constant.

Cobaltous stearate (Co) is a suitable transition metal catalyst, since it dissolves in liquid paraffin. The effect of concentrations of Co on the reaction rate is given in Table 1. The rate equation is written as follows:

$$-d[V_A]/dt = k_2[V_A][Co] + k'_2[V_A] \quad (2)$$

Here, k_2 and k'_2 are rate constants for catalysed and uncatalysed reactions, respectively. The value of k_2 was calculated to be $3.2 \times 10^{-1} \text{ M}^{-1} \text{ sec}^{-1}$ from the slope of a plotted line of $(k_1 - k'_2)$ vs $[Co]$ in Fig 1, where k'_2 is $1.84 \times 10^{-5} \text{ sec}^{-1}$. The second term, $k'_2[V_A]$, corresponds to uncatalysed reactions described below.

TABLE I. EFFECT OF CONCENTRATIONS OF COBALTOUS STEARATE ($[Co]$) ON FIRST-ORDER RATE CONSTANTS (k_1) AT 80° WITH PARTIAL OXYGEN PRESSURE OF ca 1 ATM

$10^2 [V_A]_0$ (M)	$10^5 [Co]$ (M)	$10^5 k_1$ (sec^{-1})
2.509	10.35	4.97
2.663	5.175	3.55
2.603	3.105	3.16
2.603	2.070	2.83
2.572	1.035	2.15
2.644	0	1.84

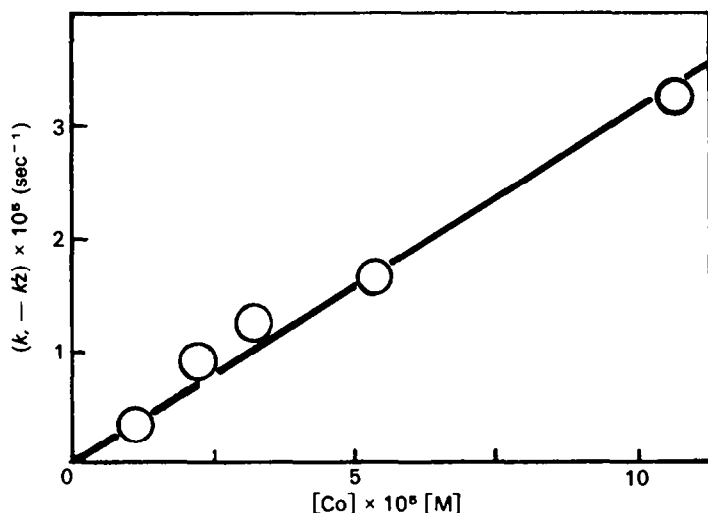


FIG 1. Effect of concentrations of cobalt stearate ($[Co]$) on rate constant ($k_1 - k'_2$) of the autoxidation of vitamin A in liquid paraffin at 80° with partial oxygen pressure (p) of 1 atm.

The effect of partial pressure of oxygen in the presence or absence of the catalyst is illustrated in Fig 2.

The figures fit the following unique rate equation:

$$-d[V_A]/dt = k_3[V_A][Co] p^a + k_4[V_A] p^b + k_5[V_A] \quad (3)$$

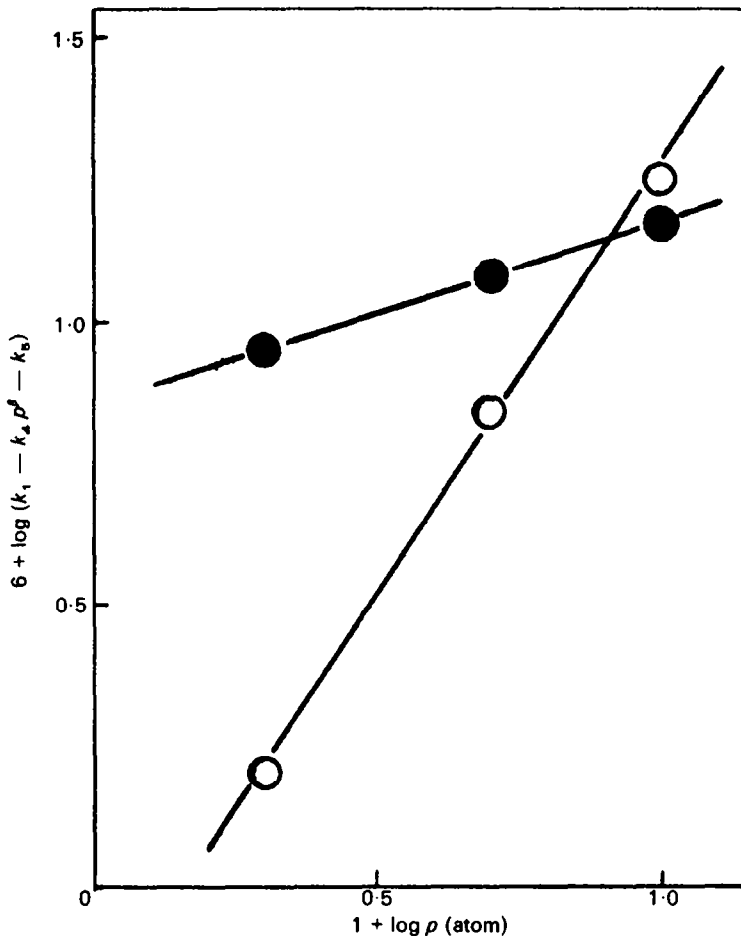


FIG 2. Effect of partial pressure of oxygen (p) on rate constants of the autoxidation of vitamin A in the presence (○) or absence (●) of cobaltous stearate of 5.18×10^{-5} M with initial concentrations of vitamin A of 2.50 – 2.81×10^{-2} M at 80° . The values of $10^5 k_1$ were 0.34 and 0.33 (sec^{-1}) at $p = 0$ (or under N_2 of 1 atm) with or without cobalt catalyst, respectively.

where k 's are rate constants, p , partial pressure of oxygen and α and β , constants representing the order in p . From a comparison of Eqs 2 and 3, it is apparent that $k_2'[\text{V}_A] = k_4[\text{V}_A]p^\beta + k_5[\text{V}_A]$.

The β value was calculated to be 0.33 from the slope of line (●) in Fig 2 in the absence of Co catalyst, and the k_4 value $1.51 \times 10^{-5} \text{ atm}^{-0.33} \text{ sec}^{-1}$ from the point of the line at p of 1.0 or $\log p$ of zero. On the other hand, another line (○) gives α of 1.48 from the slope and k_3 of $3.15 \times 10^{-1} \text{ M}^{-1} \text{ atm}^{-1.48} \text{ sec}^{-1}$ from the intercept at $\log p$ of zero by introducing 5.18×10^{-5} M as $[\text{Co}]$ into Eq: $-4.79 = \log k_3 + \log[\text{Co}]$. The last term in Eq 3, $k_5[\text{V}_A]$, represents the spontaneous degradation of vitamin A at 80° , where k_5 is $0.33 \times 10^{-5} \text{ sec}^{-1}$. The presence of thermal degradation and fractional orders in p in the kinetic law complicate the mechanistic speculation of the overall reaction. At lower temperature, however, the reaction is too slow to be studied. In fact, only 2% of vitamin A was decomposed at the same concentration in paraffin at 35° in 3 days. Hence, in general, the reaction was followed at 80° , and the term for

spontaneous decomposition, $k_3[V_A]$, was estimated independently by the decomposition under N_2 .

The reaction mixture after being kept at 80° for 4 hr was separated by column chromatography into two fractions, F_2 and F_{13} (cf Table 3). The former was unreacted vitamin A and the later the only main product, which is probably an epoxy compound according to the following data.

Remarks in IR spectra (cf Fig. 3)

1660 and 1580 cm^{-1} ($\nu_{\text{C}=\text{C}}$ of poly-ene)	} Marked decrease in strength
3020–3010 cm^{-1} ($\nu_{\text{C}-\text{H}}$ of $=\text{CH}-$)	
965 cm^{-1} ($\delta_{\text{C}-\text{H}}$ of $\text{trans} \begin{array}{c} \diagup \text{C}=\text{C} \diagdown \end{array}$)	
1260 cm^{-1} (ν_{sym} of epoxy ring)	} New bands
796 cm^{-1} (ν_{unsym} of epoxy ring or so-called "12 μ absorption band")	

Virtually no change in strength of bands assigned to OH, CH_2 and also gem-dimethyl groups on hexene ring (1360, 1375 cm^{-1}) was observed, which suggests also that C—C bond fission of the long chain in vitamin A does not occur in the reaction.

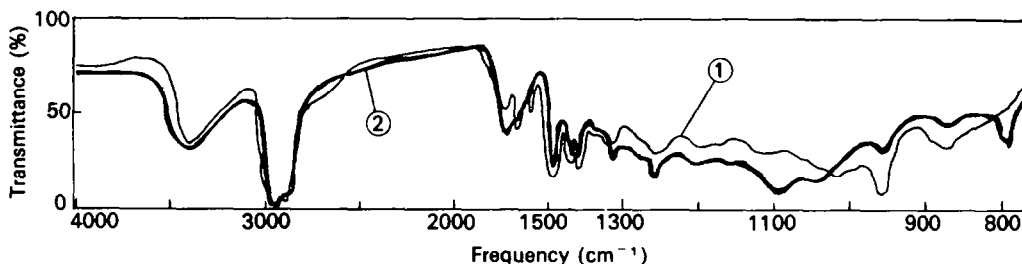
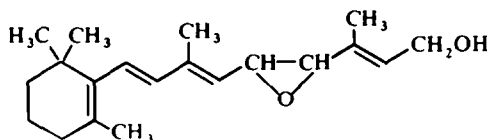


FIG 3. Chart of IR spectra of (1) vitamin A and (2) the reaction product.

The relative increase of the extinction at 1710 cm^{-1} during the reaction does not imply the formation of vitamin A aldehyde as described below. The conclusive assignment of the IR peak at 1710 cm^{-1} , which is present in vitamin A itself⁶ and increases with the disappearance of absorption bands at 1700–1600 cm^{-1} during the reaction, is still difficult and the reason for an increase of the extinction accompanied by the formation of an epoxy ring is obscure. However, the formation of a small amount of carbonyl compound cannot be ruled out, since it may not be detected by the spectrophotometry or Carr–Price reaction described below.

There is some difference in absorption spectra in both UV and visible regions between the main product (broad λ_{max} at 270–280 $\text{m}\mu$) and vitamin A (λ_{max} at 324.5 $\text{m}\mu$) or vitamin A aldehyde (λ_{max} at 389 $\text{m}\mu$). Further, the Carr–Price reaction, i.e., a colour test using a mixture of SbCl_3 and CHCl_3 , gives a more distinct difference between them: i.e., the product (λ_{max} at 570 $\text{m}\mu$), vitamin A (λ_{max} at 620 $\text{m}\mu$) and vitamin A aldehyde (λ_{max} at 664 $\text{m}\mu$).⁵ The absorption peak at 570 $\text{m}\mu$ in the colour test almost agrees with that of "chromogen 574" which is named after the characteristic λ_{max} at 574 $\text{m}\mu$ in the product of Carr–Price reaction. Troitskič⁷ has elucidated that "chromogen 574" corresponding to vitamin A epoxide (III).



Vitamin A epoxide (III)

If a large amount of cobalt stearate could be dissolved in the solvent, the catalysis by cobalt may be the only reaction in view of the value of k_3 being much higher than k_4 or k_5 in Eq 3. Then a main pathway for the formation of III may be as follows: the double bond ($-C_4=C_5-$) in vitamin A forms a complex with Co(III), produced by the oxidation of Co(II), and an O atom is introduced into the complex giving epoxide III.

EXPERIMENTAL

Materials. Vitamin A was obtained by hydrolysis of vitamin A acetate (300,000 I.U./g) dissolved in soybean oil (Sankyo Pharmaceutical Co.) and qualified by IR and UV spectra. Liquid paraffin was obtained from Nissan Petrochemical Co. and purified by fractional distillation (88–104°/20 mm) after being washed with conc H_2SO_4 . Cobaltous stearate was prepared by the reaction of cobaltous acetate with stearic acid in alcoholic soln which was a modification for the preparation of cupric stearate.⁸ The product was recrystallised from dioxan and then qualified by IR spectra and chelatometry (content of Co was 98.5% of the theoretical).

Rate measurements. Vitamin A and solvent were placed in a 100 ml flask similar to our previous report.⁹ By vigorous magnetic stirring, which enables the sufficiently rapid supply of oxygen, plots of $\log E_{324.5}$ vs time gave a straight line, indicating the first-order kinetic. The reaction products formed have no disturbing absorption near 324.5 μ . Dispersed light in a room had no effect on the reaction. The k_1 values in Eq 1 under these conditions are listed in Table 2.

TABLE 2. EFFECT OF INITIAL CONCENTRATIONS OF VITAMIN A ($[V_A]_0$) ON FIRST-ORDER RATE CONSTANTS (k_1) AT 80° IN THE PRESENCE OF COBALTOUS STEARATE OF 5.18×10^{-5} M

$10^2 [V_A]_0$ (M)	$10^5 k_1$ (sec^{-1})
0.5833	3.27
1.740	3.17
2.334	3.20
3.534	3.46
6.950	3.33

$$k_1(\text{av}) 3.28 \times 10^{-5} (\text{sec}^{-1})$$

TABLE 3. FRACTION NUMBER AND WEIGHTS OF ELUTED SUBSTANCES

F ₁	trace	F ₅		F ₁₃	10 mg
F ₂	10 mg	S	none	F ₁₄	trace
F ₃	1 mg	F ₁₁		F ₁₅	
F ₄	trace	F ₁₂	trace	S	none
				F ₄₀	

Column chromatography. A reaction product soln at 80° (ca 100 ml) was concentrated to 2 ml. A 1 ml portion of the soln was passed through a column of 30 cm × 1.5 cm* packed with alumina deactivated with 15% water. The first elution was by light petroleum (100 ml) and the second by a mixture (200 ml) of light

petroleum and MeOH (30:70). A fraction collector was set to collect each 5 g fraction. Eluted substances in each fraction were weighed, giving the data in Table 3.

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