(m/e 256; ν_{max} 1730 cm^{-1}; δ (CCl_4) 0.75 (3 H, s), 1.25–3.3 (11 H complex mm), 3.71 (3 H, s) and 6.57–7.03 (3 H, m)) in 93% yield; semicarbazone mp 216–217° dec. Benzylic oxidation[15] of the ketone **8b** with CrO_3–HOAc gave the 9-oxo derivative **13b,** mp 83–84° (m/e 270; λ_{max}^{EtOH} 222 nm (ϵ 18 900), 252 (ϵ 5670) and 325 nm (ϵ 1586); ν_{max} 1740 (s), 1715 (s), and 1615 (m)) which confirmed its assigned structure. Stereochemistry of the saturated cyclobutanones **6a** and **6b** and the respective rearranged ketones **8a** and **8b** has been assigned from their modes of formation in analogy to the respective hydrophenanthrene derivatives of established stereochemistry.[3]

To exemplify the synthetic usefulness of this rearrangement process for the introduction of an angular carboxyl group, we briefly record here transformations[3] of **8a** and **8b** to the dicarboxylic acids **9a,** mp 206–207° dec, and **9b** mp 212–213° dec, and dimethyl esters **10a,** bp 123–127° (0.05 mm) (bath temp) (ν_{max} 1725 cm^{-1}; δ (CCl_4) 0.90 (3 H, s), 1.38 (1 H, m), 1.95 (5 h, br s), 2.95 and 3.28 (2 H, partially resolved quartet, ABX system, J_{AB} = 13 Hz, J_{AX} = 3 Hz) and signal for 1 H masked under these, 3.55 (3 H, s), 3.60 (3 H, s), and 7.08 (4 H, s)), and **10b,** mp 83° (m/e 332; ν_{max} 1720 (s) and 1605 (w); δ (CCl_4) 0.90 (3 H, s), 1.31 (1 H, d, J = 7 Hz), 1.88 (5 H, br s), 2.84 and 3.25 (2 H, partially resolved quartet, ABX system, J_{AB} = 13 Hz, J_{AX} = 2 Hz) and signal for 1 H masked under these, 3.5 and 3.56 (6 H, 2s), 3.68 (3 H, s), and 6.46–7.0 (3 H, m)) in 60–65% yields through the corresponding hydroxymethylene (NaH, HCO_2Et) derivatives, followed by oxidation with alkaline hydrogen peroxide.

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(8) Mp and mmp 118° with the ketone-d_0; identity was further confirmed by mixed TLC. The comparison ir spectra (in $CHCl_3$) of this product and unlabeled ketone showed identical bands excepting the strong C–D stretch at 2160 cm^{-1} in the former. The mass spectral analysis showed the molecular ion as the base peak at m/e 242 corresponding to >99% d_2. ^1H NMR spectrum (in $CDCl_3$ at 60 MHz) of the deuterated ketone was identical with the ketone-d_0 except that the partly masked broad unresolved triplet at δ 1.96 (assigned to the C-10a proton) was absent. Moreover, the splitting pattern of the multiplets between δ 1.16 and 2.04 accounting for nine protons in the unlabeled ketone was changed and integrated to seven protons in the deuterated ketone along with a clear separation of the inner lines of the gem-$COCH_2$ protons at ca. δ 2.38 (ref 3).
(9) Mp and mmp 84–86° with an authentic sample prepared by the condensation of the acyl chloride from the known acid **12a** (ref 10) with diethyl ethoxymagnesiummalonate followed by acidic hydrolytic decarboxylation.
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(13) Compounds described here are all racemates. New compounds gave satisfactory analytical and spectral data. NMR spectra were measured at 60 MHz in a Varian T60A model. The ir spectra were taken on a PE-21 model in $CHCl_3$ solution.
(14) The diazoketone **2b,** prepared from the corresponding acid, mp 156–157° (R. Dasgupta, *unpublished results*), on cyclization with 48% *aqueous* HBF_4 in $CHCl_3$ at 5–10° gave the unsaturated cyclobutanone **4b,** mp 94–95° (ν_{max} 1765 cm^{-1}, λ_{max}^{EtOH} 262 nm (log ϵ 4.26) and 300 nm (log ϵ 3.75); δ ($CDCl_3$) 1.28 (3 H, s), 3.78 (3 H, s), 6.11 (1 H, br t, J = 5 Hz), and 6.6–7.1 (3 H, m)) in 82% yield which on catalytic hydrogenation (EtOH, Pd-C) produced a single diastereomer **6b,** mp 75° (ν_{max} 1765 cm^{-1}, δ ($CDCl_3$) 1.25 (3 H, s), 3.75 (3 H, s), 1.36–3.5 (11 H, complex m), and 6.4–7.06 (3H, m)) in ca. 95% yield.
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Laser Flash Spectroscopy of Tris(2,2′-bipyridine)ruthenium(II) in Solution

Sir:

The properties of the excited states of transition metal complexes are of great interest since these compounds often absorb strongly in the visible and might be used in solar energy conversion.[1-4] The lowest excited state of $Ru(bpy)_3^{2+}$, which is commonly considered as a triplet charge transfer excited state, $(^3CT)Ru(bpy)_3^{2+}$,[5] exhibits very peculiar properties[7] and it has been extensively used in the last few years for both energy[7,8] and electron[2,7,9-16] transfer processes. We report here a study of this excited state by laser flash spectroscopy.

The experiments were performed at room temperature with an apparatus previously described.[17,18] The neodymium laser CILAS used for excitation emits in 60-ns pulses of approximately 1 J at 530 nm and 50 mJ at 353 or 265 nm after doubling, tripling, or quadrupling its normal frequency. For excitation at 530 nm the energy of the pulse was filtered to avoid dielectric breakdown and multiphoton effects. Transient optical densities were normalized to correct for variation in excitation intensity. The detection system, which uses an automatic back off already described,[19] is able to measure absorbance values as small as 5 × 10^{-4}. The samples were deaerated by bubbling with Ar. For each laser excitation a fresh sample of the solution was used.

The absorption spectrum obtained immediately after the end of the exciting flash was practically identical for water or acetonitrile solutions and for 265, 353, or 530 nm excitation. A typical spectrum for a solution 4.7 × 10^{-5} in water (λ_{exc} 265 nm) is shown in Figure 1. The same exponential kinetics was observed for (i) the recovery of the bleaching at the maximum of the ground state absorption (453 nm), (ii) the decay of the transient absorption (360 nm), and (iii) the decay of the transient emission (610 nm). For each one of these phenomena the first-order rate constant was (1.50 ± 0.05) × 10^6 s^{-1} in water and (0.95 ± 0.05) × 10^6 s^{-1} in acetonitrile. The first-order law was unchanged by varying the $Ru(bpy)_3^{2+}$ concentration in the range 0.15 × 10^{-4} to 6.0 × 10^{-4} M. In aqueous solution the rate constant was 2.3 × 10^6 s^{-1} in the presence of air and 4.8 × 10^6 s^{-1} in the presence of 1.0 × 10^{-3} M oxygen, which gives a value of 3.3 × 10^9 M^{-1} s^{-1} for the bimolecular rate constant of the reaction of the transient with oxygen. Excitation of $Ru(bpy)_3^{2+}$ solutions in acetonitrile containing 1.0 × 10^{-3} M retinol by a 530-nm pulse (which is exclusively absorbed by the ruthenium complex) caused the appearance of the characteristic absorption at 405 of the retinol triplet.[18] The formation of retinol triplet matched the recovery of $Ru(bpy)_3^{2+}$ absorption at 453 nm. The pseudo-first-order rate constant was 4.0 × 10^6 s^{-1}, which gives a value of 2.5 × 10^9 M^{-1} s^{-1} for the bimolecular rate constant of the reaction between the transient and retinol.

The results obtained indicate that the transient absorption and emission observed are due to the same excited state of $Ru(bpy)_3^{2+}$. The emission at 610 nm of excited $Ru(bpy)_3^{2+}$ had already been studied and assigned to the so-called triplet charge transfer excited state, $(^3CT)Ru(bpy)_3^{2+}$ [5,6,20] The

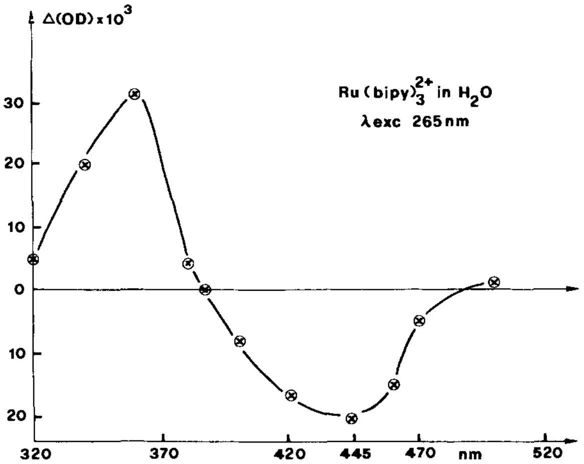

Figure 1. Differential absorption spectrum observed immediately after the end of the laser flash by exciting a Ru(bpy)$_3^{2+}$ aqueous solution with 265-nm light.

emission lifetime of (^{3}CT)Ru(bpy)$_3^{2+}$ reported by Demas and Adamson[21] in deaerated aqueous solutions (685 ns)[22] is in excellent agreement with that (665 ns) obtained in this work. Moreover, the rate constant of the reaction of the observed transient with oxygen is identical with that obtained by Demas et al.[24] for the oxygen quenching of (^{3}CT)Ru(bpy)$_3^{2+}$ ($k_q = 3.3 \times 10^9$ M^{-1} s^{-1}). Therefore, the transient observed in our flash experiments can be identified as the (^{3}CT)Ru(bpy)$_3^{2+}$ excited state and the transient absorption with λ_{max} at 360 nm can formally be assigned as a triplet-triplet transition (see below).

With excitation at 265 nm an irreversible bleaching (IB) was observed in the absence of oxygen. Its quantum yield Φ_{IB}, estimated from the oscillograms at 453 nm with a high amplification of the asymptotic part of the deflection at long times after excitation, was $\Phi_{IB} \sim 0.05$ in water and $\Phi_{IB} \sim 0.02$ in acetonitrile. With excitation at 343 and 530 nm, no irreversible bleaching was observed. Natarajan and Endicott[25] estimated that Φ_{IB} was approximately 10^{-3} in acid aqueous solutions using white light excitation of a conventional flash equipment.

Since the lifetime of the lowest "singlet" excited state of Ru(bpy)$_3^{2+}$ is much shorter ($< 10^{-10}$ s)[26,27] than the laser pulse, the only species that are present in solution immediately after excitation are the ground state and "triplet" excited state molecules. Assuming that the "triplet" excited state does not absorb at 453 nm, the depletion of ground state (S$_0$) molecules (and thus, the concentration of "triplet" excited states formed) can be calculated from the bleaching at 453 nm ($\epsilon_{S_0}{}^{453}$ 14 650 M^{-1} cm^{-1}). An upper limiting value for the extinction coefficient of (^{3}CT)Ru(bpy)$_3^{2+}$ at 360 nm, ϵ_{TT}, can then be obtained from the change in optical density at this wavelength, after correction for the ground state bleaching ($\epsilon_{S_0}{}^{360}$ 5350 M^{-1} cm^{-1}). The value obtained in this way was $\epsilon_{TT}{}^{360}$ 27 300 ± 1500 M^{-1} cm^{-1} for both water and acetonitrile solutions.

Using the previous assumptions ($\epsilon_{TT}{}^{453}$ 0 M^{-1} cm^{-1}, $\epsilon_{TT}{}^{360}$ 27 300 M^{-1} cm^{-1}), the quantum yield of (^{3}CT)Ru(bpy)$_3^{2+}$ formation has been determined by means of a relative actinometric method[29] which has successfully been used for a number of aromatic compounds.[30] Naphthalene in cyclohexane ($\epsilon_{TT}{}^{414}$ 24 500 M^{-1} cm^{-1},[31] $\Phi_T = 0.75$[30]) and benzophenone in benzene ($\epsilon_{TT}{}^{532}$ 7630 M^{-1} cm^{-1},[31] $\Phi_T = 1$[32]) were taken as references for λ_{exc} 265 and 353 nm, respectively. For both the excitation wavelengths, a value of $\Phi_T = 0.5 \pm 0.1$ was obtained for Ru(bpy)$_3^{2+}$ in water. Owing to the assumptions made, this value has to be considered as a lower limiting value of Φ_T. However, energy transfer experiments using retinol as an acceptor show that the concentration of (^{3}CT)Ru(bpy)$_3^{2+}$ measured by the ground state depletion at 453 nm (assuming $\epsilon_{TT}{}^{453}$ 0 M^{-1} cm^{-1}) and the concentration of retinol triplet measured by its absorption at 405 nm ($\epsilon_{TT}{}^{405}$ 8×10^4 M^{-1} cm^{-1})[18] are equal. Thus, the hypothesis that $\epsilon_{TT}{}^{453}$ of (^{3}CT)Ru(bpy)$_3^{2+}$ is negligible seems to be correct, and the quantum yield of "triplet" formation would then actually be 0.5 for our complex. This is in contrast with the general belief, supported by some experiments,[8a,11,26,33] that Φ_T is near to unity. Further work is in progress with other excitation wavelengths and other triplet energy acceptors in order to clarify this discrepancy.

With regard to the assignment of the observed transient absorption at 360 nm, the following points have to be taken into consideration: (i) the agreement of the three kinetic measurements, the quenching by oxygen, and the energy transfer to retinol leave little doubt that the excited state being monitored is the lowest excited state, (^{3}CT)Ru(bpy)$_3^{2+}$; (ii) the high value of the extinction coefficient shows that the observed excited state absorption is spin-allowed; (iii) the upper excited state reached with the 360 nm (27.8 kK) absorption must lie at about 45 kK above the ground state as (^{3}CT)Ru(bpy)$_3^{2+}$ lies at 17.1 kK; (iv) such a "triplet" excited state at ~45 kK could be the companion of the singlet charge transfer excited state which is present in the absorption spectrum of the ground state complex at ~47 kK; (v) the radical anion of the free ligand, bpy$^-$, exhibits an absorption band at 364 nm with ϵ 30 000 M^{-1} cm^{-1}.[34,35] On the basis of these data it is reasonable to assign the observed excited state absorption as a spin-allowed intraligand transition of the bpy$^-$ coordinated radical, which leads to an upper "triplet" charge transfer excited state of the Ru(bpy)$_3^{2+}$ complex. As our measurements were limited to $\lambda < 500$ nm, we cannot say whether (^{3}CT)Ru(bpy)$_3^{2+}$ shows absorption bands in the visible, as would be expected on the basis of the ground state absorption spectrum. However, Kirk et al.[37] found no appreciable absorption in the 550-650-nm range.

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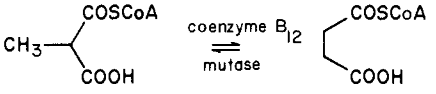
A Nonenzymic Model Intermediate for the Coenzyme B_{12} Dependent Isomerization of Methylmalonyl Coenzyme A to Succinyl Coenzyme A

Sir:

The coenzyme B_{12} dependent, enzyme catalyzed, reversible interconversion of methylmalonyl-SCoA (I) with succinyl-SCoA (II)[1] is crucial in human metabolism. It effects the return of propionic acid, resulting from amino acid and odd-chain fatty acid catabolism, to the tricarboxylic acid cycle.[2] Obstruction of the enzymic pathways necessary for the interconversion of methylmalonyl-SCoA (I) with succinyl-SCoA (II), as a consequence of any one of several possible genetic defects, leads to excesses of methylmalonic acid and propionic acid in the body and thence to some of the symptoms and malfunctions associated with the once fatal disorder pernicious anemia. In recent years it has become the practice, in appropriate instances, to monitor the levels of propionic and methylmalonic acids in the body fluids, in attempt to avert disastrous consequences from disorders related, at least in part, to pernicious anemia.[2]



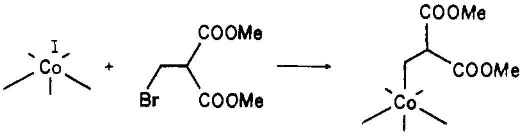
I II

In spite of the high level of interest in this important transformation (I ⇄ II), the mechanism of the reaction has remained chemically obscure. In particular, until recently,[3] there has been no nonenzymic, chemical model for such a carbon-skeleton rearrangemgnt.

A series of ingenious experiments on the enzyme system (I ⇄ II) has revealed that: the carbonyl-SCoA group is the migrating group[5] and that the migration is intramolecular.[6] The countervailing migration of hydrogen is an intermolecular reaction in which the substrate hydrogen is taken up by the 5′-methylene of the deoxyadenosine of the coenzyme, then later returned to the rearranged substrate.[7] This mechanism makes understandable the prior observation that isotopic hydrogen from deuterated or tritiated water is not incorporated into the substrate. Both the carbonyl-SCoA group and the hydrogen migrate in a way such that configuration is maintained at both termini of the rearranging system.[8]

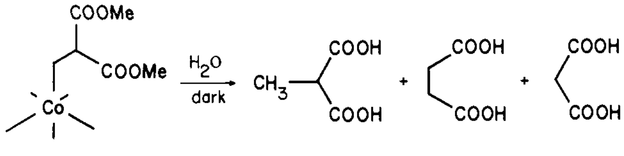
It is difficult to explore the facets discussed above and impossible to delineate the respective contributions of the enzyme and coenzyme to the rearrangement reaction in the absence of an appropriate chemical model reaction. Thus, we have begun to explore the possibility of developing a nonenzymic, chemical model for this rearrangement. This series of experiments also serves as the first test of the general applicability of a recently proposed[3,4] model intermediate for the methylitaconate ⇄ α-methylene glutarate interconversion.

Accordingly, we have treated dimethyl bromomethylmalonate (III)[9] with vitamin B_{12s}[10,11] and obtained a metastable adduct IV. The adduct IV has all the ultraviolet and visible spectral properties expected for an alkyl cobalamin[11,12] and it rapidly yields the ultraviolet and visible spectra of hydroxocobalamin upon exposure to light.



III IV

The alkyl cobalamin IV is, not unexpectedly, a very sensitive substance. It cannot be purified by extraction with phenol.[11] Even on attempted precipitation from the aqueous reaction mixture with acetone or tetrahydrofuran, the carbon–cobalt bond is cleaved to the extent of 50–70%, as judged by the changes in the visible spectrum. Thus, we have not been successful in isolating the solid adduct IV, and have been forced, as a consequence, to work with the total aqueous reaction mixture.[13] When the alkyl cobalamin IV was completely formed, the aqueous reaction mixture was extracted with ether in order to remove excess unreacted bromomethylmalonate III. The aqueous phase (pH 8–9) containing the alkylcobalamin IV was allowed to stand for 48 h at room temperature in the dark. At the end of this time, the visible spectrum showed complete conversion of IV to hydroxocobalamin (total cleavage of the carbon–cobalt bond). The reaction mixture was made acid with 10% aqueous hydrochloric acid and extracted continuously with ether for 24 h. The ether concentrate[14] was found to contain methylmalonic acid (V), 13.6%; succinic acid (VI), 3.7%; and malonic acid (VII), 18%.[16]



IV V VI VII

Isolation of pure, crystalline succinic acid (VI) from this model study of the methylmalonyl-SCoA (I) ⇄ succinyl-SCoA (II) interconversion demonstrates the fruitfulness and promise of this general approach to a chemical understanding of the mechanism of the coenzyme B_{12} dependent carbon-skeleton rearrangement reactions. It is worthwhile to summarize the attributes of this strategy. Since one has now observed *two* spontaneous rearrangements,[4] *in the dark*, at ambient temperature (20–25 °C), in aqueous solution, at or near physiological pH, of substances *identical in their carbon-skeletons* to the enzyme substrates, attached to the intact *cobalamin* nucleus, one is in position to suggest strongly that the carbon–cobalt substrate bond plays a crucial role in the rear-