THE ISOTOPE EFFECT OF TRITIUM IN THE

ACID HYDROLYSIS OF METHYL

p-METHYL-t-BENZOATE

By

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PREFACE

The hydrolysis of methyl benzoate by water in solvent
sulfuric acid, studied by Graham and Hughes (5) is slow
(half life, 7.7 hours) and is of first order with respect
to the ester but zeroth-order with respect to water in
concentrations up to 1 molar. Methyl p-toluate undergoes
hydrolysis with similar kinetics, the reaction being four
times as fast.

The isotope effect in the first-order hydrolysis of
methyl p-methyl-t-benzoate would be related to the difference
in the hyperconjugative effects of tritium and protium.

The purpose of the research presented in this thesis
was to show whether or not an isotope effect exists in the
acid hydrolysis of methyl p-methyl-t-benzoate, and if it
exists to measure it.

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CHAPTER I

HISTORICAL

The Effect of Hyperconjugation.

If electron displacement in alkyl groups resulted solely from
the operation of the inductive effect, then the rates of those reactions
which require release of electrons to the reaction region would be
in the order butyl > propyl > ethyl > methyl.

Experimental evidence that this order is not universally applicable
was first provided by J. W. Baker and W. S. Nathan (2) when they were
studying the kinetics of the combination of substituted benzylbromides
with pyridine to give benzylpyridinium bromides. They found that
p-alkyl substituents accelerate the reaction, as electron-releasing
groups should, but not in the order mentioned above as required by
the inductive mechanism. The actual order is the opposite and it
was therefore concluded that in the p-alkylbenzyl system there exists
an additional mechanism of electron release by alkyl groups which is
most strongly developed in methyl, but which becomes less when the
methyl hydrogen atoms are replaced by carbon. Baker and Nathan
associated it with the presence of the adjacent conjugated system
in the benzene nucleus. The electron pairs of the carbon-hydrogen
bonds of the methyl group are appreciably less localized than are
the electrons of the carbon-carbon bonds and are able, somewhat like
unshared electron pairs, to conjugate with the unsaturated system.

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Studies in the field have been numerous (3,4), but it has been somewhat difficult to know how much of the total effect found in a rate of reaction is due to hyperconjugation and how much to simple inductive effect.

The studies developed by Graham and Hughes (5) dealing with the kinetics of esterification of the benzoic and toluic acids, and the mechanism of hydrolysis of the esters (8), could lead to a method of differentiation between inductive and hyperconjugative effects.

The mechanism for an acid hydrolysis of methyl p-toluate in concentrations of sulfuric acid up to 1 M (9) can be expressed as follows:

$$\underline{p}\text{-CH}_3\text{-C}_6\text{H}_4\text{-COOR} + \text{H}^+ \underset{\text{fast}}{\overset{\text{fast}}{\rightleftharpoons}} \underline{p}\text{-CH}_3\text{-C}_6\text{H}_4\text{-CO-}\overset{+}{\text{O}}\text{HR}$$

$$\underline{p}\text{-CH}_3\text{-C}_6\text{H}_4\text{-CO-}\overset{+}{\text{O}}\text{HR} \underset{\text{fast}}{\overset{\text{slow}}{\rightleftharpoons}} \underline{p}\text{-CH}_3\text{-C}_6\text{H}_4\text{-}\overset{+}{\text{C}}\text{O} + \text{HOR}$$

$$\underline{p}\text{-CH}_3\text{-C}_6\text{H}_4\text{-}\overset{+}{\text{C}}\text{O} + \text{OH}_2 \underset{\text{slow}}{\overset{\text{fast}}{\rightleftharpoons}} \underline{p}\text{-CH}_3\text{-C}_6\text{H}_4\text{-CO-}\overset{+}{\text{O}}\text{H}_2$$

$$\underline{p}\text{-CH}_3\text{-C}_6\text{H}_4\text{-CO-}\overset{+}{\text{O}}\text{H}_2 \underset{\text{fast}}{\overset{\text{fast}}{\rightleftharpoons}} \underline{p}\text{-CH}_3\text{-C}_6\text{H}_4\text{-CO-OH} + \text{H}^+$$
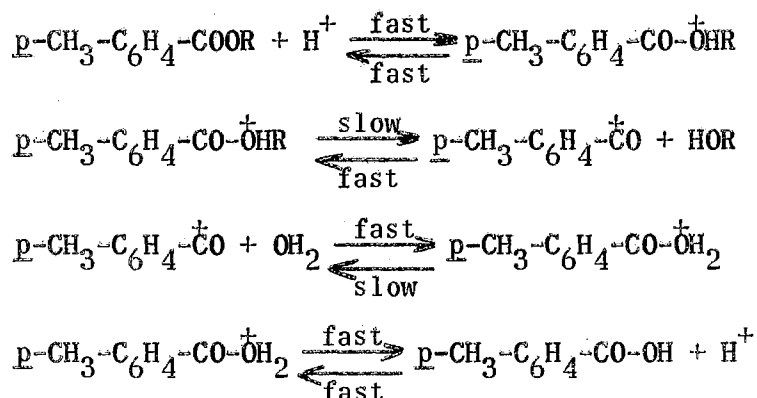
$$(\text{A}_{\text{AC}}1 \text{ mechanism})$$

The oxonium ion first undergoes a rate-controlling heterolytic fission. This produces a carbonium ion, which is then attacked rapidly by a hydroxylic molecule, as in the final step of a unimolecular solvolytic substitution. And lastly, a proton, equivalent to that originally taken up, is split off.

Isotope Effect.

Although isotopes are often defined as chemical elements with different masses but identical chemical characteristics, the latter

statement is not strictly true. Molecules containing different isotopes of the same element may react at different rates. This difference in reactivity of labeled and unlabeled molecules is called the isotope effect.

The isotope effect can be used in studying the mechanisms of reaction of organic molecules. It is generally agreed that an isotope effect will be found only if the rate-determining step of the reaction involves the breaking or formation of a bond to the isotopic atom. Under these conditions a normal molecule may react ten times as rapidly as a tritium-labeled molecule or ten per cent faster than a compound labeled with carbon-14. These differences can easily be detected and measured.

Attree, Brown, Dunn and Lonsbury (1) found in the relative rates of reaction of $C^{12}O$, $C^{13}O$ and $C^{14}O$ with oxygen that $C^{12}O$ reacts 1.016 times as fast as $C^{13}O$ and 1.043 times as fast as $C^{14}O$.

Gronowitz and Halvarson (6) report that in the competitive metalation with butyllithium of thiophene and tracer amounts of thiophene-2-t the unlabeled thiophene reacts 5.9 times as fast as the tritiated thiophene.

Isotope Effect of Tritium.

Tritium shows the largest isotope effect because its mass is three times that of protium. This is the largest relative difference in any isotopic pair.

The energy of the radiation of tritium is small, 0.0189 Mev., and its tendency to exchange with protium atoms is a further limitation in its use.

Tritium has the advantage of having a long half-life, 12.5 years,

disintegrating into helium-3 with the release of a beta particle. It is relatively inexpensive, being produced in the atomic pile by bombarding lithium with neutrons.

Work in the field has been increased since Wilzbach, Van Dyken and Kaplan (14) developed a method for determining tritium by ion-current measurement with the vibrating reed electrometer. Tritium is introduced into the ionization chamber as a gas and the disinte-gration rate measured by the radioisotope-induced ionization of the gas. Tritium in the combined state is converted into tritium gas and tritiated methane by reduction at 625° with zinc (13).

Examples of the isotope effect of tritium are numerous. Twitty (12) found that in the reaction of p-nitrobenzenediazonium chloride with benzene-t in a sodium acetate solution at 10° the normal molecule reacts 1.26 times as fast as the labeled molecule. A protium atom on a tritiated benzene molecule reacts 2.23 times as fast as a tritium atom on the same ring. A protium atom on an unlabeled benzene molecule reacts 1.15 times as fast as one on a labeled molecule.
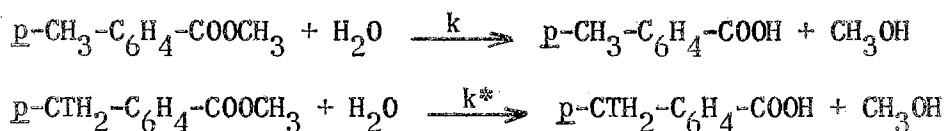
In the reduction of o- and m-nitrobenzenediazonium chloride by methanol and ethanol carrying tracer amount of tritium, it was found that protium reacts seven times as fast as tritium (10).

CHAPTER II

INTRODUCTION TO EXPERIMENTAL WORK

The object of this investigation was to measure the intermolecular isotope effect in the acid hydrolysis of methyl p-methyl-t-benzoate. The intermolecular isotope effect is the ratio of reactivities of a normal molecule and an isotopically labeled molecule for a particular reaction, represented in this case by k^*/k.

The reactions involved are:

$$p\text{-}CH_3\text{-}C_6H_4\text{-}COOCH_3 + H_2O \xrightarrow{k} p\text{-}CH_3\text{-}C_6H_4\text{-}COOH + CH_3OH$$

$$p\text{-}CTH_2\text{-}C_6H_4\text{-}COOCH_3 + H_2O \xrightarrow{k^*} p\text{-}CTH_2\text{-}C_6H_4\text{-}COOH + CH_3OH$$

The equation which relates the rate constant to the radioactivity is:

$$\frac{k^*}{k} = \frac{\log\ (1-rf)}{\log\ (1-f)} \qquad \text{(See Appendix I for derivation)}$$

f = fraction reacted.

r = the ratio of the specific activities of the products and the reactants. The molar activity was measured in microcuries per millimole.

It may be seen from the above equation that it is necessary to measure the extent of reaction and to isolate, purify and measure the activity of the product at two extents of reactions. The activity was measured when the reaction was 5% and 100% complete in order to obtain the greatest difference in specific activities. (See figure 1)

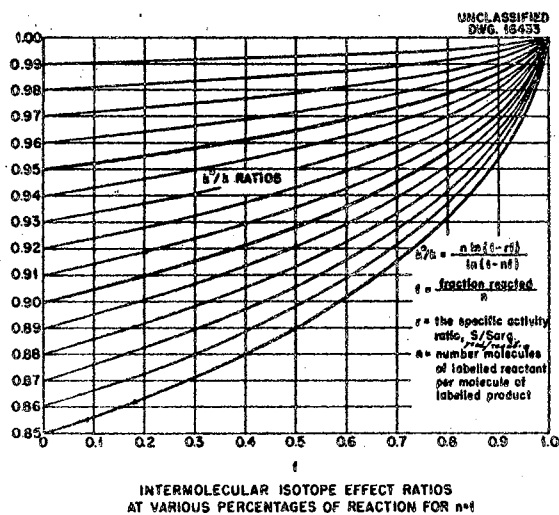The first step was to check for possible difficulties in the

INTERMOLECULAR ISOTOPE EFFECT RATIOS
AT VARIOUS PERCENTAGES OF REACTION FOR n=1

Figure 1

separation of p-toluic acid from the sulfuric acid solution. This was done by putting p-toluic acid in contact with sulfuric acid for half an hour and then recovering the p-toluic acid by extraction with ether, washing of the ether solution with sodium carbonate, precipitation of the p-toluic acid again with hydrochloric acid, extraction of the acid with ether, and evaporation of this ether in a weighed beaker.

In order to check for the kinetics of the acid hydrolysis, runs were made with methyl p-toluate in solution of 99-100% sulfuric acid. It was found that at 25° the rate of reaction was convenient for controlled experiments, the half life being approximately 1.9 hours.

Tritiated toluene was made by treating benzylmagnesium chloride with tritiated water. This tritiated toluene reacted with acetic anhydride via the Friedel-Crafts method and the tritiated p-methyl-acetophenone obtained was oxidized with chlorine and sodium hydroxide to the sodium salt of the tritiated p-toluic acid. Esterification

with methyl alcohol gave the ester. Purification of this ester
was accomplished by dissolving it in methyl alcohol at room temperature,
neutralizing the excess of acid with sodium hydroxide, filtering at
room temperature the solid formed and filtering again at -78°. The
ester was stored in a cold room.

Hydrolyses in which some and all of the ester was destroyed
were performed in 99-100% solution of sulfuric acid, the extent of
reaction being approximated from the 1.9 hours half life.

The acid was recovered by the same method mentioned in the
first step, but after the last extraction the acid was crystallized
from water and dried. A final purification was accomplished by
sublimation in the vacuum line.

Samples of this acid were used to determine specific radio-
activities.

Some ester was completely hydrolyzed in alcoholic base in order
to avoid sulfonation of the ring by the 99-100% sulfuric acid.

The amount of exchange of tritium atoms between the methyl group
of the p-toluic acid and the hydrogen atoms of the sulfuric acid was
studied. This was done by putting p-toluic acid in contact with
tritium-labeled sulfuric acid for thirty minutes. The p-toluic
acid was recovered and purified by the method used before. Radioassay
of this acid showed negligible amounts of tritium.

Conductivity measurements of mixtures of 96.5% sulfuric acid
and fuming sulfuric acid (21% free sulfur trioxide) were made in the
last experiment in order to be sure that the sulfuric acid used in
the partial acid hydrolysis was 99-100% pure.

CHAPTER III

EXPERIMENTAL WORK

Recovery of p-Toluic Acid from Concentrated Sulfuric Acid.

A 69.5-milligram sample of p-toluic acid and 15 milliliters of
98% sulfuric acid were placed in a 50-milliliter erlenmeyer flask.
After the mixture had stood for half an hour it was poured into 150
milliliters of ice and water, then the p-toluic acid was extracted
three times with 50-milliliter portions of ether. The ether solution
was washed three times with 15 milliliters of a 5% solution of sodium
carbonate. This aqueous solution was acidified with hydrochloric
acid and again extracted three times with 15-milliliter portions of
ether. The ether solution was dried with anhydrous calcium sulfate
and poured into a weighed beaker.

The acid recovered gave a 103.4% yield.

Hydrolysis of Methyl p-Toluate.

A 1.7445-gram sample of methyl p-toluate prepared for Taylor
(11) was dissolved in 25 milliliters of 99-100% sulfuric acid prepared
from fuming sulfuric acid (35% free sulfur trioxide) and 96.5% sulfuric
acid solution. The reaction mixture was allowed to stand for 8 minutes
which was the calculated time required for a 5% hydrolysis based on
the work of Graham and Hughes (5). The p-toluic acid formed was
isolated by the above procedure.

The extent of reaction effected was not greater than 9.7%.

Preparation of Methyl p-Methyl-t-Benzoate.

Eight grams of magnesium turnings was added to a dry three-neck flask containing a condenser, stirring apparatus, and a closed separatory funnel, and dried for 24 hours.

About 12 milliliters of dry ether was placed with the magnesium turnings. Forty-two grams of benzyl chloride in 100 milliliters of dry ether was added dropwise from the separatory funnel and the mixture was heated to boiling. The reaction started and the external heating was stopped.

After the reaction had ceased, three milliliters of tritiated water (53.4 microcuries/millimole) prepared by Dr. Hodnett (7) and ether were added with stirring from the separatory funnel to the products of the reaction. Finally hydrochloric acid was added until the reaction had stopped.

The ether layer was separated, washed several times with water and dried with anhydrous calcium sulfate. The ether was distilled off in the vacuum line.

About 35.2 grams of tritiated toluene, 90 grams of aluminum chloride and 30 milliliters of carbon disulfide were placed in a three-neck flask fitted with a stirrer, a separatory funnel and a condenser. Then 38 grams of acetyl chloride was added dropwise through the funnel. To complete the reaction the flask was heated on a steam bath at about 80°. When the reaction had stopped the contents of the flask were poured into ice and water. Additional ether was added in order to extract the tritiated p-methylacetophenone. After the ether was distilled, the p-methylacetophenone was obtained by vacuum distillation.

This p-methyl-t-acetophenone was dissolved in about 100 milli-liters of methyl alcohol and placed in a flask with about 60 milliliters of a 30% solution of sodium hydroxide. Chlorine was passed through the mixture until a drop of the liquid liberated iodine from a solution of potassium iodide.

The products of the reaction were placed in the vacuum line and the alcohol distilled off. The solution of the sodium salt of the tritiated p-toluic acid was acidified with hydrochloric acid and the precipitated acid dissolved in the minimum amount of a 1:1 mixture of alcohol and water. The acid was purified by cooling this solution to $0°$ and filtering the precipitated acid.

The acid obtained (12 grams) was dissolved in an excess of methyl alcohol, placed in a flask with one milliliter of concentrated sulfuric acid, as catalyst, and heated to reflux for twelve hours.

The products obtained were distilled off in order to separate the unreacted methyl alcohol. Then the ester left was purified by dissolving it in ether, drying the solution on a steam bath, dissolving it again in methyl alcohol, adding two drops of phenolphthalein and titrating with sodium hydroxide. The solid obtained was filtered and the solution cooled to $-78°$. The crystals of methyl p-methyl-t-benzoate (about 13 grams) were stored in the cold room.

The overall yield of the complete process was about 26%. The activity yield was about 8%.

Partial Hydrolysis of Methyl p-Methyl-t-Benzoate.

A sample of methyl p-methyl-t-benzoate weighing 1.5-2.0 grams was dissolved in 25 milliliters of 99-100% sulfuric acid in a 50-milliliter flask. The flask was in a bath controlled at $25°$. After

eight minutes the contents of the flask were poured into 150 milli-
liters of ice and water. Then the tritiated p-toluic acid formed
was extracted three times with 50-milliliter portions of ether. The
ether solution was washed three times with 15 milliliters of a 5%
solution of sodium carbonate. This solution was acidified with hydro-
chloric acid and the tritiated p-toluic acid obtained was again
extracted three times with 15-milliliter portions of ether. The ether
was distilled off from this solution and the acid was dissolved in
the minimum amount of boiling water. The p-methyl-t-benzoic acid
separated as a solid when the solution was cooled. The acid was
dried in the desiccator and sublimed in the vacuum line.

The radioassay of the p-methyl-t-benzoic acid was initiated
by weighing a 4.5-5.5 milligram sample into a combustion boat and
sealing it in an evacuated reaction tube along with a 4.5-5.5 milli-
gram sample of distilled water, 100 milligrams of nickelic oxide
and 1 gram of zinc. The ampoule was then broken inside the reaction
tube. The tube was placed in a furnace at 625° for three hours for
reduction of the p-methyl-t-benzoic acid which formed hydrogen and
methane gas.

After cooling, the gases were transferred to an ionization
chamber by means of the vacuum line. The chamber was then filled to
atmospheric pressure with methane and attached to the vibrating reed
electrometer for measurement of the activity. The chamber had previously
been evacuated and filled with methane and the background read.

Calculation of the Activity

1 curie = 3.7×10^{10} disintegrations/second.
1 disintegration of tritium in methane = 3.09×10^{-17} coulombs.
1 curie - 11.43×10^{-7} amperes.

Resistor No. 3 = 0.96 x 10^{10} ohms.

Resistor number 3 was changed later to 1.0 x 10^{10} ohms.

1 curie = 10.976 x 10^3 volts.

1 μc. = 10.976 mv.

1 mv. = 0.091 μc.

With the change in the resistor number 3:

1 mv. = 0.088 μc.

As only a portion of the gas (1/F) is transferred to the chamber, a correction must be made. It is:

$$F = \frac{297.8 - \dfrac{\text{weight of tube}}{2.5}}{256.7}$$

Therefore:

$$\mu c/mg = \frac{mv. \times 0.091 \times F}{\text{wt. sample in mg.}}$$

This hydrolysis was repeated using another sample of the same ester. Results of these assays are given in Table I.

Complete Acid Hydrolyses of Methyl p-Methyl-t-Benzoate.

A sample of methyl p-methyl-t-benzoate weighing 100-150 milligrams and 15 milliliters of 99-100% sulfuric acid were placed in a 50-milliliter flask for 7 days at room temperature. The separation and purification procedure mentioned in the partial hydrolysis of methyl p-methyl-t-benzoate was followed exactly in the complete hydrolysis. Other samples were run for 24 hours. Results of these assays are given in Table II.

Complete Alkaline Hydrolysis of Methyl p-Methyl-t-Benzoate.

A 1.5-milliliter sample of a solution made from 0.4315 grams of methyl p-methyl-t-benzoate and 5 milliliters of methyl alcohol was placed in a 50-milliliter flask with 5 milliliters of 0.544 N

sodium hydroxide, the reaction time being 7 days. After that time
the methyl alcohol was distilled off in the vacuum line and the tritiated
p-toluic acid was precipitated with concentrated hydrochloric acid.
The procedures for purifying and assaying the p-methyl-t-benzoic
acid obtained in the acid hydrolysis were exactly followed. This
hydrolysis was repeated with a sample of the ester recovered from
the partial acid hydrolysis. Results of these assays are given in
Tables III and V.

Tritium Exchange Between Methyl p-Methyl-t-Benzoate and Sulfuric Acid.

A 0.2114-grams sample of p-toluic acid and 7.86 grams of tritiated
sulfuric acid (prepared from 7.5 grams of fuming sulfuric acid, 21.4%
free sulfur trioxide, 0.27 grams of tritiated water, 53.4 microcuries/
millimole, and 0.09 grams of distilled water) were placed in a 50-
milliliter flask for 30 minutes. After that time the products of the
reaction were poured into 150 milliliter of ice and water. Again
the procedures for the separation, purification and assay of the
p-methyl-t-benzoic acid in the acid hydrolysis of methyl p-methyl-t-
benzoate were used here. Assay of this acid showed 0.094, 0.080,
0.044, and 0.056 μc/mmole or an average of 0.069 μc/mmole. This
value is less than 1% of that for the labeled ester, indicating
insignificant exchange.

Partial Hydrolysis With Recovered Ester.

In order to obtain new figures for which correction for decay
would not be necessary, recovery of the ester used in the runs of
partial hydrolysis was made.

The ether solutions of the unreacted ester were evaporated and
the ester recovered was purified by dissolving it in ether, drying

the solution on a steam bath, dissolving it again in methyl alcohol, adding two drops of phenolphthalein and titrating with sodium hydroxide. The solution was then cooled to -78°. The crystals of methyl p-methyl-t-benzoate were stored in the cold room.

A new partial hydrolysis was made following exactly the procedures above mentioned.

In order to be sure that the partial acid hydrolysis was made in 99-100% sulfuric acid and was following a first order mechanism conductivities of mixtures of 96.5% sulfuric acid and fuming sulfuric acid (21% free sulfur trioxide) were determined (15).

A conductivity apparatus with the conductivity cell submerged in 96.5% sulfuric acid was prepared. After fuming sulfuric acid had been added and the mixture had been stirred, the conductivity of the mixture was determined. Several determinations were made with different mixtures until the minimum conductivity was exactly measured.

Data concerning assays of the labeled acid are given in Table IV.

TABLE I

SAMPLES OF PARTIAL ACID HYDROLYSIS

Number 1-partial hydrolysis.

August 25, 1956
Samples: 1 . . . . . 7.06 μc/mmole
2 . . . . . 7.10 μc/mmole
Average: 7.08 ± 0.02 μc/mmole

October 15, 1956
Samples: 3 . . . . . 7.19 μc/mmole
4 . . . . . 7.15 μc/mmole
Average: 7.17 ± 0.02 μc/mmole

Number 2-partial hydrolysis.

September 15, 1956
Samples: 1 . . . . . 7.44 μc/mmole
2 . . . . . 7.29 μc/mmole
Average: 7.36 ± 0.08 μc/mmole

October 15, 1956
Samples: 3 . . . . . 7.17 μc/mmole
4 . . . . . 7.18 μc/mmole
5 . . . . . 7.14 μc/mmole
6 . . . . . 7.15 μc/mmole
7 . . . . . 7.24 μc/mmole
Average: 7.17 ± 0.03 μc/mmole

Correction for decay to August 25, 1956.

Number 1-partial hydrolysis:
August 25, 1956 samples . . . . . 7.08 μc/mmole
October 15, 1956 samples. . . . . 7.22 μc/mmole
Average: 7.15 ± 0.07 μc/mmole

Number 2-partial hydrolysis:
September 15, 1956 samples . . . . . 7.39 μc/mmole
October 15, 1956 samples . . . . . 7.23 μc/mmole
Average: 7.28 ± 0.06 μc/mmole

Overall average: 7.23 μc/mmole.

TABLE II

SAMPLES OF COMPLETE ACID HYDROLYSIS

Number 1-complete hydrolysis. (7 days)

       September 15, 1956
            Samples: 1 . . . . . 7.19 μc/mmole
                     2 . . . . . 7.15 μc/mmole

       October 15, 1956
            Samples: 3 . . . . . 7.18 μc/mmole

Number 2-complete hydrolysis. (7 days)

       October 15, 1956
            Samples: 1 . . . . . 7.07 μc/mmole

Number 3 and 4-complete hydrolysis. (7 days)

       November 15, 1956
            Samples: 1 . . . . . 7.23 μc/mmole
                     2 . . . . . 7.18 μc/mmole
                     3 . . . . . 7.26 μc/mmole

Number 5 and 6-complete hydrolysis. (24 hours)

       November 15, 1956
             Samples: 1 . . . . . 7.49 μc/mmole
                     2 . . . . . 7.44 μc/mmole
                     3 . . . . . 7.50 μc/mmole

TABLE III

SAMPLES OF COMPLETE BASIC HYDROLYSIS

Number 1--complete hydrolysis. (7 days)

January 10, 1956

Samples: 1 . . . . . . 7.18 μc/mmole
2 . . . . . . 7.06 μc/mmole
3 . . . . . . 7.19 μc/mmole
4 . . . . . . 7.21 μc/mmole

Average: 7.16 ± 0.05 μc/mmole

Correction for decay to August 25, 1956.

Overall average complete hydrolysis: 7.32 μc/mmole.

TABLE IV

ACID HYDROLYSIS FROM THE RECOVERED ESTER

Partial hydrolysis.

Samples: 1 . . . . . . 7.02 μc/mmole
2 . . . . . . 7.17 μc/mmole
3 . . . . . . 7.02 μc/mmole
4 . . . . . . 7.15 μc/mmole
5 . . . . . . 7.20 μc/mmole

Average: 7.11 ± 0.07 μc/mmole.

TABLE V

BASIC HYDROLYSIS FROM THE RECOVERED ESTER

Complete hydrolysis. (7 days)

Samples: 1 . . . . . . 7.18 μc/mmole
2 . . . . . . 7.20 μc/mmole
3 . . . . . . 7.18 μc/mmole
4 . . . . . . 7.16 μc/mmole

Average: 7.18 ± 0.01 μc/mmole.

CHAPTER IV

INTERPRETATION OF THE RESULTS

The fact that the difference in the radioactivities of the product after partial acid hydrolysis and after complete hydrolysis is very small, and that the experimental values overlap, indicates that if an isotope effect exists, it is very small and its value lies inside the error limits of the analytical methods used.

Tritium exchange between the tritium of the sulfuric acid and the protium of the p-toluic acid has been shown to be negligible. Here the probability of obtaining an exchange should be much greater because the tritium atoms of the sulfuric acid could exchange with every one of the protium atoms of the methyl group and those of the ring. If this exchange, as previously mentioned, is negligible in the period of 30 minutes allowed, the reverse tritium exchange, between the tritium of the methyl group and the protium of the sulfuric acid, is highly improbable.

The carbonium ion formed in the course of the acid-catalyzed hydrolysis involves the carbon atom of the carboxyl group, out of the ring. The tritium atom is 6 carbon atoms away from the carboxyl group. This distance should work towards a diminishing of the isotope effect, which checks with the results of the experiments shown in this investigation.

CHAPTER V

SUMMARY

The tritium isotope effect in the acid hydrolysis of methyl p-methyl-t-benzoate has been measured. The isotope effect is very small and its value lies inside the error limits of the analytical methods used.

Tritium exchange between tritium labeled sulfuric acid and p-toluic acid has been also determined. The tritium exchange has been shown to be negligible.

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APPENDIX

Derivation of Rate Equation.

k = rate of normal reaction

k^* = rate of labeled reaction

c_0 = initial concentration of the normal reacting species

c_0^* = initial concentration of the labeled reacting species

x = decrease of concentration of the normal reacting species after the lapse of time t.

x^* = decrease of concentration of the labeled reacting species after the lapse of time t.

$$k = \frac{1}{t} \ln \frac{c_0}{c_0 - x}$$

$$k^* = \frac{1}{t} \ln \frac{c_0^*}{c_0^* - x^*}$$

If

$$\frac{c_0^*}{c_0} = a \quad ; \quad \frac{x^*}{x} = a' \quad \text{and} \quad \frac{a'}{a} = r$$

$$c_0^* = a \cdot c_0 \quad ; \quad x^* = a'x = a \cdot r \cdot x$$

$$\frac{k^*}{k} = \frac{\frac{1}{t} \ln \frac{c_0^*}{c_0^* - x^*}}{\frac{1}{t} \ln \frac{c_0}{c_0 - x}}$$

If reaction is allowed to proceed until $\frac{x}{c_0} = f$

$$\frac{k^*}{k} = \frac{\ln \frac{a \cdot c_0}{a \cdot c_0 - a \cdot r \cdot f \cdot c_0}}{\ln \frac{c_0}{c_0 - f \cdot c_0}} = \frac{\log (1 - r \cdot f)}{\log (1 - f)}$$

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VITA

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Candidate for the Degree of

Master of Science

Thesis: THE ISOTOPE EFFECT OF TRITIUM IN THE ACID HYDROLYSIS OF
METHYL p-METHYL-t-BENZOATE

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