THESIS

PRESENTED FOR THE DEGREE

OF

MASTER OF SCIENCE AND HONOURS

UNIVERSITY OF NEW ZEALAND

1955

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THE PREPARATION OF 2-NITRO-1-NAPHTHOIC
ACID, AND THE ALKALINE HYDROLYSIS OF
ETHYL 2-NITRO-1-NAPHTHOATE AND ETHYL
6-NITRO-1-NAPHTHOATE IN ETHANOL-WATER
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ABSTRACT OF THESIS

Possible methods for the preparation of 2-nitro-1-naphthoic acid, a derivative of naphthalene which has not previously been synthesised, have been reviewed and it has been prepared from 2-nitro-1-methylnaphthalene. A mechanism has been proposed for the condensation of aromatic nitromethyl compounds with diethyl oxalate. Ethyl 2-nitro-1-naphthoate and ethyl 6-nitro-1-naphthoate have been prepared and the kinetics of their alkaline hydrolysis in ethanol-water (85:15 by weight) have been studied over the temperature range 50 - 65°C. In following the kinetics of hydrolysis, a conductivity method has been used. Energies and entropies of activation have been calculated for these hydrolysis reactions. Certain anomalies in activation energy and entropy values for the alkaline hydrolysis of nitro substituted ethyl 1-naphthoates, compared with those obtained for nitro substituted ethyl benzoates, have been discussed.
One of the most fundamental and intriguing objectives of modern chemistry is the correlation of the chemical reactivities of compounds with their structure. The reactivity of a compound depends on both its electronic and geometrical configurations but, as a variation of the geometrical structure of a molecule also results in a variation of its electron distribution, we cannot, in general, attribute a change in reactivity to a variation of one of these structural aspects alone. However, variations of the geometrical structure may be only local in effect, while the consequent electronic changes are usually not local and may influence reaction sites beyond the range of the geometrical influence.

Thus in compounds of types (I) and (II) above, the effect of a substituent group (Y) on the reaction of a side chain (X) is successfully explained in terms of electronic considerations alone. On the other hand, in compounds of type (III) the reactivity of the side chain is influenced, in general, both by the electronic and geometrical nature of the substituent group.

In 1930 Hammett derived an expression to correlate quantitatively the reactivity of the side chain (X) with the nature of the substituent (Y) in compounds of types (I) and (II). The Hammett equation is

$$\frac{-\Delta G^+}{R T} = \log \frac{k}{k_0} = \sigma \rho$$

where $\Delta G^+$ is the relative free energy of activation, $k$ and $k_0$ are the rate or equilibrium constants for the reaction of the substituted and the unsubstituted compounds respectively, $\sigma$ is a substituent constant which depends solely on the nature and position of Y and $\rho$ is a reaction constant.
which depends only on the reaction and the conditions under which it takes place. The reactions for which \( k \) and \( k_0 \) are the rate or equilibrium constants must take place by the same mechanism. Substituent constants were originally derived by defining the reaction constant for the dissociation of substituted benzoic acids as unity and calculating the appropriate substituent constants. These were then used to derive reaction constants for other reactions.

Since the postulation of the above equation considerable interest has been shown in the reactivities of benzene derivatives. Taft has extended the Hammett equation to compounds of type (III) and to aliphatic compounds by introducing a parameter which allows for the geometrical nature of the substituent. The Hammett equation has also been extended to disubstituted benzene derivatives where one substituent exerts a constant electronic and geometrical influence on the reactivity of the side chain.

![Diagrams of compounds IV, V, and VI](image)

Compounds of type (IV), (V) and (VI), where \( Z \) is an invariable substituent and \( X \) the side chain, are typical examples.

The conditions under which the Hammett equation will be applicable can be expressed more objectively in terms of energy considerations. The Arrhenius equation for a reaction

\[ k = A e^{-\frac{E}{RT}} \]  

(2)

(where \( E \) and \( A \) are constants)

can be rewritten in the form

\[ \ln k = D - \frac{E}{RT} \]  

(3)

(where \( D = \ln A \))
Thus if the value of the rate constant of a compound for a particular reaction is measured at several different temperatures, then \(-\log k\) should be a linear function of \(1/T\) and have a gradient given by \(E/2.303R\). Using the value of \(E\) so obtained, substitution in equation (3) gives a value for \(D\).

If Arrhenius energies (E) and frequency factors (D) are obtained in this manner, both for the substituted and the non-substituted compounds, then by application of the three equations:

\[
\Delta \Delta G^\ddagger = \Delta G^\ddagger - \Delta G_0^\ddagger = -RT \ln \frac{E}{E_0} \tag{4}
\]

\[
\Delta \Delta H^\ddagger = \Delta H^\ddagger - \Delta H_0^\ddagger = E - E_0 \tag{5}
\]

\[
\Delta \Delta S^\ddagger = \Delta S^\ddagger - \Delta S_0^\ddagger = R(D - D_0) \tag{6}
\]

(where the suffix 0 refers to the unsubstituted compound) the appropriate values of the relative free energy of activation (\(\Delta \Delta G^\ddagger\)), the relative heat of activation (\(\Delta \Delta H^\ddagger\)) and the relative entropy of activation (\(\Delta \Delta S^\ddagger\)) can be calculated. It has been shown that for the Hammett equation to hold either, the relative entropy of activation must be zero, and hence, from equation (7), the relative heat of activation is equal to the relative free energy of activation, or the relative entropy of activation must be proportional to the relative heat of activation and hence the latter is proportional to the relative free energy of activation.

\[
\Delta \Delta G^\ddagger = \Delta \Delta H^\ddagger - T \Delta \Delta S^\ddagger \tag{7}
\]

In the reactivities of benzene derivatives of types (I) and (II) studied, (e.g., by Watson), an analysis of this type shows that the relative entropy of activation is negligible and therefore the Hammett equation is applicable. It can be shown also to be applicable to compounds of types (IV), (V) and (VI), where the compounds to which the values are relative are the corresponding ones without the substituent group (Y).

By comparison with the interest shown in reactivities in the benzene series, reactivities of naphthalene derivatives have been neglected. This is accounted for, in part, by the
more complex nature of the problem. Whereas there is only one possible benzene derivative containing a single side chain (VII), there are two possible isomeric naphthalene derivatives, (VIII) and (IX).

(Substitution in positions 9 and 10 of the naphthalene nucleus is of no importance in this discussion as it leads to a breakdown in the aromaticity of the naphthalene nucleus.)

In any investigation of the effect of a substituent group on the reactivity of a side chain in naphthalene derivatives there are thus two series of compounds to investigate, depending on the position of the side chain (X). The Hammett equation is assumed to be applicable to compounds of types (VIII) and (IX) substituted in positions such that the geometrical nature of the substituent does not affect the reactivity of the side chain.

For instance compounds of type (X) are regarded as a special case of types (V) or (VI) and compounds of type (XI) as a special case of compounds of types (I) or (II).

Only four workers have so far investigated the problem of the influence of a substituent group, at different positions in the naphthalene ring, on the reactivity of a side chain. \[\text{Werbach (1893)}\] determined the dissociation constants of the ten then available aminonaphthalene-sulphonic acids. \[\text{Bryson (1949–51)}\] has determined the Pka values for the fourteen nitronaphthylammonium ions and the dissociation constants for the thirteen known aminonaphthalene-
sulphonic acids, and has interpreted his results in terms of the qualitative electronic theory. Price (1952-) has initiated a programme for the determination of substituent constants in the naphthalene series from the alkaline hydrolysis of the ethyl esters of substituted 1- and 2- naphthoic acids in dioxan-water (70:30 by weight). He has also used the acid dissociation constants of substituted 1-naphthoic acids in ethanol-water (78:22 by weight) for evaluating some of the same substituent constants, and has found that the values obtained by both methods agree quite well. Finally, Fischer has completed the first part of a programme of research, initiated at this College, into the effects of substituents on the rates of reaction of side chains in the naphthalene series. The reaction series chosen for study was the alkaline hydrolysis of substituted ethyl 1-naphthoates in ethanol-water (85:15 by weight). The corresponding reaction series in benzeno derivatives has been studied in detail and certain similarities with this series are expected. The nitro substituent was chosen for the initial work as Bryson's results gave rise to certain general expectations about its behaviour. Furthermore, Hamnett substituent constants for the nitro group can be calculated from Bryson's work for ethyl x-nitro-1-naphthoates where x is 3, 4, 5, 6 or 7, and comparison with values obtained in the present investigation is possible.

Only two investigators have so far measured the rates of reaction of substituted naphthalene derivatives at more than one temperature. Price measured the rates of alkaline hydrolysis of several 5-, 6-, 7- and 8-substituted ethyl 2-naphthoates at two temperatures and derived values for the activation energy and entropy in each case. He found that the relative entropy of activation, compared to ethyl 2-naphthoate, was close to zero, and thus the Hamnett equation can be assumed to be applicable. Fischer measured the rates of alkaline hydrolysis of ethyl 3-nitro-1-naphthoate and ethyl 4-nitro-1-naphthoate at four temperatures and derived the values of the Arrhenius energy and frequency
factor for each. As was expected from the known -I, -M properties of the nitro substituent, the rates of alkaline hydrolysis of the 3- and 4-nitro substituted esters were greater than that of the unsubstituted ester and thus a negative value of the relative free energy of activation was obtained. By analogy with the values calculated from the alkaline hydrolysis of 3- and 4-nitro substituted ethyl benzoates it was expected that the influence of the nitro group would cause the relative heat of activation to be negative while the relative entropy of activation would be close to zero. Fischer, however, found that the relative heat of activation was actually markedly positive while the relative entropy of activation was comparatively large. The only feasible explanation would appear to be a change in the mechanism of the reaction between the unsubstituted and the substituted esters, but Fischer considered this to be unlikely.

The subject of the present work is the determination and interpretation of the rate constants for the alkaline hydrolysis of ethyl 2-nitro-1-naphthoate and ethyl 3-nitro-1-naphthoate. This involved the preparation of the previously unreported 2-nitro-1-naphthoic acid and this is considered in detail in section (3) of this work. The method employed to follow the hydrolyses was a conductivity one similar to that used by Fischer. The value of the rate constant for the hydrolysis of ethyl 1-naphthoate, determined by Wilson by a titration method, was also checked by conductivity measurements.

In the ethanol-water medium used for the hydrolyses not all the base present exists as hydroxide ions. Goldin and Long have investigated the equilibrium between hydroxide and ethoxide ions in aqueous ethanol solutions at 25°C. and from their figures it can be calculated that in 85% ethanol, at 25°C., about 40% of the total base present exists as hydroxide ions. Fischer has shown that observed
rate constants obtained from measurements performed in aqueous ethanol are related to the true rate constants by the equation

\[ k_{\text{observed}} = F \cdot k_{\text{true}} \]

where \( F \) is the proportion of total base existing as hydroxide ions, and is a constant for a fixed medium. It can be shown that values of Arrhenius energies calculated using observed values of the rate constants are independent of any change in \( F \) caused by a variation in the concentration of base. Moreover, Caldin and Long's figures suggest that the variation of \( F \) with the concentration of base would be small in 35% aqueous ethanol and therefore no significant error would be expected in the values of Arrhenius frequency factors calculated using observed rate constants. Caldin and Long suggest that \( F \) should be independent of temperature. Any change in \( F \) due to temperature can, however, be shown to produce no effect on the relative values of activation energy and entropy calculated. As only relative values of the rates were required no attempt has been made to evaluate the true reaction constants.
(2) PREPARATION OF 2-NITRO-1-NAPHTHOIC ACID

NOMENCLATURE

1. The system of numbering used for the naphthalene and acenaphthene rings conforms to that given in "The Ring Index", (Patterson and Capell. Reinhold Publishing Company 1940), and illustrated below.

```
  8
  7 6
  5 4
  3
  1 2
```

```
  5
  4
  3
  2 1
```

2. Naphthalene-1:8-dicarboxylic acid is referred to throughout as naphthalic acid.

3. Melting points given are uncorrected.

4. Reference melting points are listed in brackets after the measured figures. Unless otherwise stated they are the highest quoted in "Elseviers Encyclopaedia of Organic Chemistry".

5. All microanalyses of compounds were performed at Otago University College.

6. In reaction diagrams the significance of the colours used for reaction paths is as follows: (i) purple - preparations already reported by other workers, (ii) red - new preparations reported in this work and (iii) green - preparations attempted unsuccessfully in this work.

(I) Introduction

A survey of the relevant literature showed that likely methods for the production of 2-nitro-1-naphthoic acid could be listed under four main headings.

A. The preparation of 2-nitro-1-methylnaphthalene and its subsequent oxidation, either directly or indirectly, into the acid.

B. The preparation of 2-nitro-1-naphthylamine and its conversion to the acid, either (i) through 2-nitro-1-naphthonitrile, followed by hydrolysis...
or (ii) through 2-nitro-1-bromonaphthalene by
the formation of an organo-metallic derivative
and its subsequent carboxylation.

C. The preparation of 2-nitro-1-naphthalic acid and
its subsequent mercuration and decarboxylation.

D. The preparation of 2-amino-1-naphthoic acid,
followed by diazotisation and a Sandmeyer re-
action.

A discussion of each of these four methods is given
below.

A. 2-Nitro-1-methylnaphthalene had already been pre-
pared by two alternative methods, neither of which gave
high yields. Attempts had been made to oxidise it using
both alkaline permanganate and dilute nitric acid in sealed
tubes. The latter condition has been used to convert 1-
nitro-1-methylnaphthalene into 1-nitro-1-naphthoic acid."

However the acids produced in this case would appear to
have been di- or tricarboxylic ones. Reducing the strength
of the oxidising conditions resulted in leaving the 2-nitro-
1-methylnaphthalene unchanged. That this happens is ex-
plicable in terms of the steric inhibition to oxidation of
the methyl group provided both by the adjacent nitro group
and the neighbouring peri position in the naphthalene ring.

In a somewhat similar case, namely an attempt by Lessner to
oxidise 2-methyl-1-nitronaphthalene, only an inseparable
mixture of acids was obtained.

Indirect methods of oxidation involve the formation
of some derivative of the methyl group which is more readily
oxidised than the methyl group itself. The use of N-
bromosuccinimide to produce 2-nitro-1-bromomethyl-naphthalene
suggested itself. Lodder failed to brominate the methyl
group in ortho-nitrotoluene by this method and this sug-
gested steric hindrance would prevent the formation of the
above compound. However the use of benzoyl peroxide often
promotes bromination with this reagent. 19 In the preparation
of 1-nitro-2-naphthoic acid, Meyer formed 1-nitro-2-naphthyl-

20
pyruvic acid as an intermediate by condensing 1-nitro-3-methylnaphthalene with diethyl oxalate and an analogous procedure was feasible in this case.

(i) 2-Nitro-1-naphthylamine can be quite readily prepared. Its conversion to 2-nitro-1-naphthonitrile has not been reported but should offer no great difficulty. However the hydrolysis of this to the acid is unlikely. In the isomeric case of 1-nitro-2-naphthonitrile it had been found that hydrolysis under alkaline conditions leads to the formation of 1-hydroxy-3-naphthoic acid, while 50% sulphuric acid leaves it unchanged, even after prolonged boiling. An attempt to oxidise it through the use of 100% ortho phosphoric acid, a method reported to be suitable for the hydrolysis of sterically hindered nitriles, had previously been made by the Author, without success. In view of the greater steric inhibition to hydrolysis expected in this case production of the acid by this method was considered unlikely.

(ii) 2-Nitro-1-bromonaphthalene can be obtained from 2-nitro-1-naphthylamine in reasonable yield. A study of the literature on the production of magnesium and lithium derivatives from bromo-aromatic compounds revealed few compounds where deactivating groups were also present in the ring, and none where nitro groups were present. The use of n-butyl lithium as a metallation agent offered more success. This is reported to be successful in cases where lithium and magnesium themselves fail to react. By means of it, for instance, 2-bromobenzoic acid has been converted to phthalic acid in low yield.

The advantage of this method, if successful, would be that only three steps are involved from a readily obtained starting material. 3-Nitrocinnamophenone has been produced by nitration of cinnamophenone under special conditions in yields of about 20%. Its oxidation to "nitronaphthalic acid has also been reported, though it was stated that much degradation took place, and no yield is quoted.
However, if suitable quantities of this material could be obtained, mercuration by an analogous procedure to that used for 4- and 3-nitronaphthalic acids should be possible.

\[ \text{3-nitronaphthalic acid} \rightarrow \text{3- and 6-nitro-1-naphthoic acids} \]

\[ \text{4-nitronaphthalic acid} \rightarrow \text{4- and 5-nitro-1-naphthoic acids} \]

Thus 2-nitronaphthalic acid might be expected to yield a mixture of 2- and 7-nitro-1-naphthoic acids which could be separated easily by esterification of the latter by hydrogen chloride in ethanol, as steric hindrance to esterification should leave the former unchanged.

2. 2-Amino-1-naphthoic acid has been prepared from 4:5 benzi sat. However the production of 4:5 benzi sat itself presents considerable difficulties. Furthermore replacement of the amino group by a nitro one is likely to have a low yield.

It was therefore decided to attempt:-

I. The preparation of an organo-metallic derivative from 2-nitro-1-bromonaphthalene and its subsequent carboxylation.

2. The preparation of 2-nitronaphthalic acid, followed by mercuration and hydrolysis.

3. The preparation of either (A) 2-nitro-1-bromomethyl-naphthalene, and its subsequent hydrolysis and oxidation, or (B) 2-nitro-1-naphthypruvic acid and its subsequent oxidation.
(i) Acetylation.
(ii) Nitration.
(iii) Hydrolysis.
(iv) Separation.

(i) Diazotisation.
(ii) Sandmeyer reaction.

Fig 1
Discussion

All three methods of synthesis enumerated above were attempted and they are discussed below. Only method 3B was found to be suitable for the preparation of 2-nitro-l-naphthoic acid.

**METHOD 1**

(See Fig. 1)

1-Naphthylamine (I) was acetylated and subsequently nitrated to give a mixture of 2- and 4-nitro-aceto-l-naphthalides. Hydrolysis yielded a mixture of 2- and 4-nitronaphthylamines (II and III). Hodgson and Walker investigated the separation of these compounds and discovered that, by passing a stream of dry hydrogen chloride into a solution of the amines in nitrobenzene, 4-nitro-l-naphthylamine hydrochloride was quantitatively precipitated. After filtration the 2-nitro-l-naphthylamine was recovered by shaking with concentrated sulphuric acid, to precipitate it as its sulphate. Alternatively, by shaking a solution of the amines in glacial acetic acid with concentrated hydrochloric acid, the 4-nitro-l-naphthylamine hydrochloride was precipitated and the 2-nitro-l-naphthylamine could be recovered by dilution with water. Hodgson suggested the former was preferable but in practice it was found to present considerable manipulative difficulties. Both the precipitate of the 4-nitro-l-naphthylamine hydrochloride and the 2-nitro-l-naphthylamine sulphate were of a fine flocculent nature and filtration was extremely difficult, especially as the solution had a deleterious effect on the filter paper. The alternative method was found to be both simpler and less tedious.

2-Nitro-1-bromonaphthalene (IV) was prepared from 2-nitro-l-naphthylamine as described by Hodgson. Attempts were made, by various methods, to form an organo-metallic derivative from this. Even after long periods of heating under reflux no reaction was observed with magnesium in dry ether. Mechanical stirring or the use of promoters such as iodine or ethyl bromide had no apparent effect.
Gilman has shown that organic halides that do not react satisfactorily with metallic magnesium or lithium to give organo-metallic compounds will often undergo a halogen-metal interconversion reaction with such substances as n-butyl lithium, to give the required compound.

\[ n-{\text{Bu}}_2\text{-Li} + RX \rightarrow n-{\text{Bu}}_2\text{-}X + R\text{-Li} \]

where \( X \) = halogen.

n-Butyl lithium was prepared by adding the calculated quantity of n-butyl bromide, in anhydrous ether, to lithium chips in anhydrous ether. The apparatus was flushed with dry oxygen free nitrogen and, once the reaction had started, was kept at \(-10^\circ\text{C}\), by means of an acetone dry-ice bath. The 2-nitro-1-bromonaphthalene was added at room temperature with constant mechanical stirring, which was continued for half an hour after the addition. Carboxylation was performed by pouring the mixture on to a finely powdered mass of dry ice. After leaving for an hour the mixture was hydrolysed with water and extracted with ether. On extraction with saturated sodium bicarbonate solution and subsequent acidification with dilute hydrochloric acid, no significant amount of solid acidic material was found.

That no organo-metallic derivative could be formed is not surprising. As already stated the presence of the nitro group appears to act as a powerful deactivating centre.
(VII) Nitration
   (ii) Separation

(VIII) Oxidation
   (ii) Separation

(IX) Separation
   (ii) Hydrolysis

(X) Hydrolysis

(V) Hydrolysis

(XI) Hydrolysis

Fig 2
Nitration ofacenaphthene (VI) by the usual methods, such as concentrated nitric acid in glacial acetic acid, leads to the formation of 5-nitroacenaphthene (VII). However, if diacetil-orthonitric acid or benzoyl nitrate are used as nitrating agents then reasonable quantities (20-30%) of 3-nitroacenaphthene (VIII) are formed, even though 5-nitroacenaphthene still predominates. Separation of the 5- and 5-nitro derivatives is relatively easy because of the limited solubility of the former compound in acetic anhydride at room temperature.

3-Nitroacenaphthene was prepared using diacetil-orthonitric acid. This reagent was employed, in spite of the larger yields obtained with benzoyl nitrate, on account of its greater stability and ease of preparation. Satisfactory yields were obtained.

The only information Morgan gives with regard to the oxidation of 3-nitroacenaphthene is that (a) Potassium permanganate leaves it unchanged and (b) an excess of boiling chromic acid solution oxidizes it, with considerable degradation, to a mixture of 1:2-dihydroxyacenaphthene (X) and 2-nitronaphthalic acid (IX). These were separated by extracting their solution in ether with aqueous boric-acetate solution and subsequent acidification to yield the 2-nitronaphthalic acid.

However from the oxidation of 10 gram samples only quite small (less than 0.1 gram) quantities of the acid were obtained. The method of oxidation employed was to dissolve the 3-nitroacenaphthene in hot glacial acetic acid and then to add solid sodium dichromate, over a period of time with constant mechanical stirring, followed by boiling under reflux for several hours. These conditions have proved effective in oxidising acenaphthene to naphthalic acid and 5-nitroacenaphthene to 4-nitronaphthalic anhydride. Several attempts were made to obtain satisfactory quantities of the acid by variation of the oxidising conditions. The
amount of dichromate, the amount of acetic acid and the
time of reflux were all varied without significant increase
in the yield. In order for oxidation to take place stringent
conditions are necessary and any attempt to obtain more
2-nitronaphthalic acid by making the oxidising conditions
milder only leads to unchanged 3-nitroacenaphthene.

Thus it would appear that unless another method of
oxidation is found the only procedure for obtaining useful
quantities of 2-nitronaphthalic acid is to oxidise large
quantities of 3-nitroacenaphthene. It is possible that
the use of N-bromosuccinimide would yield 1-bromo-2-nitro-
acenaphthene (1:2-dibromo-3-nitroacenaphthene is unlikely
by analogy with the failure of 2-nitro-1-methylnaphthalene
to react with N-bromosuccinimide – see later). If this is
formed alcoholic potassium hydroxide would probably yield
3-nitroacenaphthylene which may be more readily oxidised.

The production of 3-nitronaphthalic acid in reasonable
quantities is highly desirable as there is no a priori
reason why mercuration would not succeed. (The overall
yield in the mercuration of 1- and 3- nitronaphthalic acids
is similar.) Whether the mercuration yielded 2-nitro-1-
naphthoic (V) or 7-nitro-1-naphthoic acid (XI), or more
probably a mixture of both, it would still be eminently
useful as a synthetic method.
METHOD 3
(See Figs. 3 and 4)

Only two feasible methods were available for the production of 2-nitro-1-methylnaphthalene (XVIII). It has been shown to be present among the nitration products of 1-methylnaphthalene but only in very small quantities. It was first prepared by Veesly by a method involving a total of seven steps:

1-Naphthol → 2:4-dinitro-1-naphthol → 2:4-dinitrochloronaphthalene → 2:4-dinitro-1-naphthylmalonic acid → 2:4-dinitro-1-naphthylacetic acid → 2:4-dinitro-1-methylnaphthalene → 2-nitro-l-aminol-1-methylnaphthalene → 2-nitro-1-methylnaphthalene.

The yields are low for some of the steps and thus the method is impractical for the production of useful amounts of 2-nitro-1-methylnaphthalene. 2:4-Dinitro-1-methylnaphthalene has also been prepared by the action of fusing nitric acid on 1-methylnaphthalene (XII), but the reaction was violent and the probable yield low. The overall yield of 2-nitro-1-methylnaphthalene from 1-methylnaphthalene would be expected to be very low.

Gerhard has produced 2-nitro-1-methylnaphthalene in 60% yield by the de bromination of 2-bromo-2-nitro-1-methylnaphthalene (XVII) using an experimental procedure due to Edwards. The overall yield from 1-methylnaphthalene (XII) was about 2% but only three steps were involved (see Fig. 3).

Two procedures were used for the bromination of 1-methylnaphthalene. Fieser considered that the best method for the production of 2-bromo-1-methylnaphthalene (XVI) was one involving the preparation of 1-methylnaphthalene-4-sulphonic acid and its subsequent bromination by an aqueous solution of bromine and potassium bromide. A yield of 28% (equal to that quoted by Fieser) was obtained using this method.

Direct bromination was previously considered inferior to this method on account of the variety of products formed.
For instance Meyer found that bromination in the dark, using carbon disulphide as a solvent and heating on a water bath, gave rise to the following compounds which he separated by fractional distillation: 55% 1-bromo-1-methyl-naphthalene, 20% 1-bromomethyl-naphthalene, 10% 1-bromo-1-bromomethyl-naphthalene and 10% unchanged 1-methyl-naphthalene. Similarly Robinson obtained a 55% yield of 2-bromo-1-methyl-naphthalene by bromination, in the cold, in carbon tetrachloride. This was increased to 70% by fractional recrystallisation of the picrates of the products formed.

However it was found that bromination of pure 1-methyl-naphthalene, (as supplied by L Light and Co., England), in carbon tetrachloride at -5°C, in the absence of direct sunlight, led to an almost quantitative yield of 1-bromo-1-methyl-naphthalene provided small amounts of iron powder and iodine were added to act as a catalyst. No other products could be detected. It must be assumed that bromine atoms, which would lead to side chain attack, are virtually absent under the above conditions.

Vesely prepared 4-bromo-3-nitro-1-methyl-naphthalene (XVII) by the nitration of 4-bromo-1-methyl-naphthalene with a mixture of concentrated nitric and sulphuric acids below 100°C. In practice it was found that two alternative procedures could be followed. Either the nitrating mixture could be added, drop by drop and with constant stirring, to the 4-bromo-1-methyl-naphthalene below 5°C, or alternatively the addition could be reversed. Both procedures led to manipulative difficulties. In the former a viscous substance formed as a skin on the surface and then, as the addition progressed, solidified into lumps which interfered with the stirring of the reaction mixture. It was found that these were best removed by a glass ladle and washed with large quantities of water. After the addition of all the reagent the mixture was stirred for a further fifteen minutes. All the solid, putty-like material
was removed and washed extensively with water. No further material could be recovered from the reaction mixture, even after dilution with excess water. When the nitrating mixture was added to the 1-bromo-1-methylnaphthalene it was found that the reaction mixture solidified before the calculated quantity of nitrating mixture could be added. As efficient stirring was then impossible only polynitration would have taken place if more nitrating mixture had been added.

After extensive washing with water the product was purified by a tedious process involving continuous extractions and fractional recrystallisation with both petroleum ether and ethanol. A good criterion of purity of the substance was the change in form from amorphous to crystalline, This occurred when the melting point was ca. 116°C.

Yields by both methods varied widely. In the former method yields of from 15 → 30 grams of product were obtained per 100 grams of 1-bromo-1-methylnaphthalene nitrated. In the latter method the figure was 20 → 40 grams. The reason for the low yields would appear to be polynitration in the first case and a combination of polynitration and incomplete reaction in the second, where less than the theoretical amount of nitrating mixture was added. (This was shown to be true in the second case where a distillation of the residues, both from the extraction of the reaction mixture and those obtained by boiling down the solvents used for extraction, yielded some 1-bromo-1-methylnaphthalene.

However it is not feasible to recover much of it this way as decomposition occurs if the distillation is continued too long. It would perhaps be possible to recover it by extraction with ethanol as the 1-methylnaphthalene would have a larger solubility in this solvent than would the polynitratd residues). The reason for the variations in yields is not clearly understood but temperature control and efficient stirring are essential to a reasonable yield.

An attempt was also made to nitrate 1-bromo-1-methyl-
naphthalene with diacetyl-orthonitric acid, but the conditions proved too mild and no reaction occurred.

Debromination of 2-nitro-1-bromo-1-methynaphthalene was carried out by boiling it under reflux with acetic anhydride and fuming nitric acid in pyridine and then pouring into excess 5% acetic acid. If this was left for twelve hours before filtration it was found that the amount of product left in solution was negligible. The purity of the pyridine appeared to affect the yield of 2-nitro-1-methynaphthalene and hence it was redistilled before use. The best solvent for the extraction of the solid material collected was found to be petroleum ether, though ethanol can also be used. No yield of either unchanged reactant or of product could be obtained by decomposing the solid residues, left after extraction, with hot hydrochloric acid.

An attempt was made to brominate the methyl group in 2-nitro-1-methylnaphthalene but, even after a long period of reflux, N-bromosuccinimide in the presence of a small amount of benzoyl peroxide failed to react. This is probably accounted for by steric inhibition.

An attempt was also made to prepare 2-nitro-4-bromo-1-bromomethynaphthalene (XV) by nitrating 4-bromo-1-bromomethylnaphthalene (XIV). (See Fig. 3).

Methods for the preparation of 4-bromo-1-bromomethynaphthalene (XIV) found in the literature involved the action of bromine on 4-bromo-1-methylnaphthalene (XVI) under an arc lamp. However the availability of N-bromosuccinimide as a side-chain brominating agent outdates this method.

Two methods were used to produce 4-bromo-1-bromomethynaphthalene. In the first 1-bromomethylnaphthalene (XIII) was prepared as an intermediate by the action of N-bromosuccinimide on 1-methylnaphthalene (XII). Locally boiled these compounds together under reflux for thirty hours in carbon tetrachloride but, by using a little benzoyl peroxide as a free radical promoter, satisfactory yields were
recorded after boiling under reflux for three hours. An attempt made to brominate 1-bromomethylnaphthalene in glacial acetic acid by the use of bromine led to the production of some 1-bromo-1-bromomethylnaphthalene but the yield was low and the material obtained by distillation under reduced pressure was very crude. This is probably partly caused by the low solubility of 1-bromo-1-methyl-
naphthalene in glacial acetic acid. Bromination in carbon tetrachloride using a carrier catalyst would probably be more efficient. However in view of the lacrymatory nature of 1-bromomethylnaphthalene, which makes its handling difficult, and of the excellent yields obtained, the second method was preferable. Here 1-bromo-1-methylnaphthalene (xvi) was brominated with N-bromosuccinimide, in the presence of benzoyl peroxide, to give an excellent yield of 1-bromo-1-
bromomethylnaphthalene. Attempts were made to nitrate this in the 2-position using an analogous procedure to that used for 1-bromo-1-methylnaphthalene. As 1-bromo-1-
bromomethylnaphthalene is a solid it must be added to the nitrating mixture and not vice-versa. It was found that the temperature was extremely difficult to control and sudden rises led to polynitration. In cases where the temperature was effectively maintained at about 50°C, the only substance isolated was unchanged reactant. At temper-
atures above this the reaction became violent and led to polynitration.
KOEt, (CO$_2$H$_2$)$_2$
In cold 20 hours.

NaOEt, (CO$_2$H$_2$)$_2$
Under reflux In 45 minutes.

Hydrolysis.

(i) Oxidation.
(ii) Separation.

Oxidation.
Mayer prepared 1-nitro-2-naphthoic acid by the oxidation of 1-nitro-2-naphthylpyruvic acid obtained by heating 1-nitro-2-methylnaphthalene under reflux with diethyl oxalate in the presence of sodium ethoxide. In an analogous attempt with 4-nitro-1-methylnaphthalene the only product he isolated was 2:1:1'-dinitronaphthyl-1:1'-ethane (XXIV).

An attempt was made to condense 2-nitro-1-methylnaphthalene with diethyl oxalate under similar conditions. It was heated under reflux with diethyl oxalate and sodium ethoxide in alcohol under a variety of conditions of concentration and time of reflux. In all cases the predominant product was 2:2'-Dinitronaphthyl-1:1'-ethane (XXI). However, definite amounts of 2-nitro-naphthyl-1-pyruvic acid were also produced, but the yields were small and variable and the alternative procedure described below was found to be more efficient. The dinitronaphthyl-ethane produced above was almost insoluble in most common organic solvents except hot chlorobenzene and this made its separation and purification relatively easy. Attempts to oxidise this compound in glacial acetic acid using sodium bichromate showed it to be very resistant to oxidation. The small amount of acidic material produced after prolonged boiling under reflux was probably a benzene-tricarboxylic acid.

The potassium derivative of the ethyl ester of 1-nitro-2-naphthylpyruvic acid has been produced by the condensation of diethyl oxalate with 1-nitro-2-methylnaphthalene under the influence of potassium ethoxide in the cold. This compound was converted to 1-nitro-2-naphthylpyruvic acid by leaving it in contact with water, or to the
ester by decomposing it with dilute hydrochloric acid. Wislicenus found that increasing the amount of ethoxide above the theoretical requirement led to the production of some \( \text{dinitronaphthyl-2:2'}-\text{ethane} \) which became the only product when twice the theoretical amount of ethoxide was employed. Excess diethyl oxalate was found to repress the formation of this compound. An attempt was made to prepare \( \text{2-nitro-1-naphthylpyruvic acid (XXI)} \) by an analogous procedure but the yield of the acid was only about 30% and the predominant product still \( \text{2:2'-dinitronaphthyl-1:1'}-\text{ethane} \). Accordingly the condensation was attempted in the presence of a large excess of diethyl oxalate. It was found that, providing all the reactants used were of high purity, a high yield of the potassium derivative was produced. Unless the diethyl oxalate was freshly distilled and the alcohol 'super dry', then the yield decreased markedly. Leaving the potassium derivative in contact with water for twelve hours did not give \( \text{2-nitro-1-naphthylpyruvic acid} \) as expected but rather its ethyl ester (XX). Decomposition of the potassium derivative by dilute hydrochloric acid also gave this ester. The ester was hydrolysed by warming it with the calculated amount of potassium hydroxide in alcohol till the precipitate of the potassium derivative first formed had dissolved and then adding the solution to a large excess of water. Acidification after a few hours led to \( \text{2-nitro-1-naphthylpyruvic acid} \). \( \text{2-Nitro-1-methylnaphthalene} \) and \( \text{2:2'}-\text{dinitronaphthyl-1:1'}-\text{ethane} \) are produced as by-products. An explanation of this and a discussion of the probable mechanisms involved in the reactions above appears in Appendix A.

There were two feasible methods for the oxidation of the \( \text{nitronaphthylpyruvic acid} \) obtained above. \( \text{1-Nitro-2-naphthylpyruvic acid} \) has been oxidized by both alkaline permanganate solution, to give a mixture of \( \text{1-nitro-2-naphthaldehyde} \) and \( \text{1-nitro-2-naphthoic acid} \), and by hypobromite solution, to give an unquoted yield of the acid. An attempt to produce \( \text{2-nitro-1-naphthoic acid} \) by the latter
method proved unsatisfactory. The products isolated by oxidation at room temperature were (a) an alkali soluble material, m. pt. 280°C, probably a tricarboxylic acid and (b) an alkali-insoluble residue which made up the bulk of the product. This was shown to contain bromine and on heating decomposed at 61°C. This was probably a dibromide, a product which Mayer expected to get by the action of hypobromite solution on 1-nitro-2-naphthaldehyde. On warming in dilute hydrochloric acid the suspected dibromide decomposed, losing bromine, to give a mixture of acidic and non-acidic materials.

Oxidation by alkaline permanganate was found to be best carried out at room temperature. After separation of the manganese dioxide formed, by use of a centrifuge as filtration is slow and tedious, the organic matter was extracted with ether and subsequently with aqueous bicarbonate solution to divide it into acidic and non-acidic layers. 2-Nitro-1-naphthaldehyde was recovered from the ethereal layer. It is very soluble in organic solvents such as ether, acetone and ethanol but can be recrystallised from methanol or petroleum ether. It failed to give an aldehyde test with Schiff's reagent in alcohol, probably on account of steric inhibition to the reaction. However reaction with semicarbazone hydrochloride led to a semicarbazone. On acidification of the bicarbonate layer obtained above a brown precipitate of melting point ca. 120 - 120°C, was obtained. A prolonged system of fractional recrystallisation from ethanol:water (1:3) yielded 2-nitro-1-naphthoic acid after the equivalent of at least twelve recrystallisations. Recrystallisation is made difficult by the presence of an impurity which is present as an oil in the hot solvent but solidifies on cooling. A more elegant procedure for purification was found to be the preferential esterification of the impurities by a Fischer-Speier esterification procedure. 6-Nitro-1-naphthoic acid, when heated under reflux in ethanol, was known to be unaffected by a stream
of hydrogen chloride\(^2\) and as the esterification of 2-nitro-
1-naphthoic acid should be more difficult the same was
expected to hold. This was found to be true and the
acidic material recovered from esterification of the crude
material above was crude 2-nitro-1-naphthoic acid. It was
still impure but preferential extraction of the acid in
aqueous ethanol made its further purification fairly simple.
The acid was found to be soluble in organic solvents such
as acetone, ethanol and ether and had a definite solu-
bility in water. It was also produced by oxidising a solu-
tion of the aldehyde, in acetone, with an aqueous solution
of potassium permanganate. The yield was about 45% but
most of the unchanged aldehyde was recovered.
ACETO-1-NAPHTHALIDE

100 grams of 1-naphthylamine was added to a mixture of 90 c.c. of acetic anhydride and 650 c.c. of glacial acetic acid in a 1000 c.c. beaker. The mixture was heated to 100°C. and kept at this temperature for five minutes. On cooling aceto-1-naphthalide was precipitated. It was collected in a Buchner funnel and washed with chilled ethanol. The yield was 120 grams or 93%.

NITRATION OF ACETO-1-NAPHTHALIDE

100 grams of recrystallised aceto-1-naphthalide was added slowly with mechanical stirring to 700 c.c. of concentrated nitric acid in a 5-necked flask. The temperature was maintained below 5°C. by means of an ice-salt bath. An efficient chain stirrer was necessary to avoid solidification of the mixture after about half the addition. The addition was completed in one hour and the mixture was stirred for a further half an hour, and then added to two litres of water. The precipitate was collected in a Buchner funnel and washed extensively with water and then with 100 c.c. of chilled ethanol.

The mixture of acetylated nitro-naphthylamines obtained above was hydrolysed by boiling under reflux for eight hours with a mixture of 100 c.c. of concentrated sulphuric acid, 250 c.c. of ethanol and 150 c.c. of water. On pouring into 1500 c.c. of water a mixture of 2-nitro-1-naphthylamine and 4-nitro-1-naphthylamine was precipitated. It was collected in a Buchner funnel, washed with water and ethanol and dried.

SEPARATION OF 2- AND 4-NITRO-1-NAPHTHYLAMINES

A. In Nitrobenzene

The mixture of nitro-naphthylamines obtained above was dissolved in 1200 c.c. of dry nitrobenzene. A dry stream of hydrogen chloride was passed into the solution until white fuming was apparent (ca. half an hour). The solution was then filtered and the precipitate washed with nitrobenzene. After collection of the total nitrobenzene
filtrate and washings, the precipitate was washed with benzene to remove nitrobenzene, and then dried. On trituration with water crude 2-nitro-1-naphthylamine was obtained. The nitrobenzene solution was then treated with 20 c.c. of concentrated sulphuric acid. The precipitate was filtered off and treated as above to yield crude 2-nitro-1-naphthylamine. After recrystallisation from 90% formic acid 12.5 grams of 2-nitro-1-naphthylamine was obtained, m. p. 136°C. (133°C.)

B. In Glacial Acetic Acid

A mixture of nitro-naphthylamines obtained by the nitration and subsequent hydrolysis of 50 grams of aceto-1-naphthalide was dissolved in 500 c.c. of glacial acetic acid. 40 c.c. of concentrated hydrochloric acid was added and the precipitate formed on stirring was filtered off and triturated with water to give impure 2-nitro-1-naphthylamine. The acetic acid filtrate was diluted with 150 c.c. of water and again filtered. This precipitate consisted of mixed 2- and 4-nitro-naphthylamines which were separated by fractional recrystallisation.) Further dilution with water yielded 2-nitro-1-naphthylamine. Recrystallisation from 90% formic acid gave 11 grams, m. p. 134°C.

2-NITRO-1-BROMONAPHTHALENE

9 Grams of sodium nitrite was dissolved with vigorous stirring in 60 c.c. of concentrated sulphuric acid at 50°C. The solution was heated to 70°C, till all solid matter was dissolved. To this solution was added below 15°C, a solution made by dissolving 19 grams of recrystallised 2-nitro-1-naphthylamine in 240 c.c. of hot glacial acetic acid and rapidly cooling to room temperature.

The mixture obtained above was added below 20°C, with mechanical stirring, to a solution of 15.5 grams of cuprous bromide in 120 c.c. of hydrobromic acid. A deep violet solution was obtained. The mixture was stirred for half an hour and then heated to 50°C, in a water bath. After leaving overnight the solution was filtered through a Buchner funnel
and the precipitate washed with water. After recrystallisation twice from ethanol, 13.5 grams of 2-nitro-1-bromonaphthalene was obtained, m. pt. 94°C. (98°C.), yield 55%.

3-NITRO-1-ACENAPHTHIENE

400 c.c. of acetic anhydride was cooled to -10°C.
and 80 c.c. of concentrated nitric acid (1:42) slowly added while the temperature was kept below 0°C. This solution at -5°C. was added, all at once, to a suspension of 80 grams of acenaphthene in 1000 c.c. of acetic anhydride at -5°C., with efficient stirring. The solution went yellow and the temperature rose to 17°C. On cooling precipitation of a yellow solid took place. It was cooled to 11°C. and then filtered through a Buchner funnel. The filtrate was added to 10 litres of water to yield crude 5-nitroacenaphthene. The precipitate of crude 3-nitroacenaphthene was washed with chilled acetic anhydride and then with chilled acetic acid. It was then recrystallised twice from acetic acid to give 19.4 grams of 3-nitroacenaphthene (18.8%), m. pt. 117.5°C. (151.5°C.)

1-BROMOMETHYLNAPHTHALENE

27 Grams of 1-methylnaphthalene, 0.2 grams of benzoyl peroxide and 32.75 grams of N-bromosuccinimide were heated under reflux for three hours in 50 c.c. of carbon tetrachloride. Another 50 c.c. of carbon tetrachloride was then added, the mixture cooled and the succinimide filtered off. After washing with chilled 0.5% sodium hydroxide solution and water, and drying over anhydrous magnesium sulphate, most of the carbon tetrachloride was removed by distillation. The residue was distilled under reduced pressure and the fraction boiling 167 - 176°C. (17 mm.) was collected. This solidified to give 26 grams of crude 1-bromomethyl-naphthalene (65.6%). This was recrystallised twice from petroleum ether (m. pt. 600 - 60°C.) to yield 26 grams (60%), m. pt. 49.5°C. (530 - 550°C.)
**4-Bromo-1-methylnaphthalene**

(A) 80 Grams of 1-methylnaphthalene was stirred mechanically with 150 c.c. of pure concentrated sulphuric acid for six hours. The mixture became red in colouration. The mixture was then added to 200 c.c. of water and the precipitate filtered off. It was redissolved in 350 c.c. of hot water and 75 grams of potassium chloride added. When this was dissolved, the solution was cooled, yielding a white precipitate of 1-methylnaphthalene-1-sulphonic acid which was filtered off and washed with water.

This was dissolved in one litre of water and to this, at 50°C., was added a solution of 50 grams of bromine and 70 grams of sodium bromide in 200 c.c. of water. On cooling a yellow oil formed on the bottom of the beaker. This was extracted with ether. Retreatment of the aqueous solution with more bromine yielded a little more oil. The ethereal extract was washed successively with 5% sodium bisulphite solution, 2 N. hydrochloric acid and 5% sodium hydrosulphide solution. After drying over anhydrous calcium chloride the ether was distilled off and the residue distilled under reduced pressure. The fraction b.p. 157 - 165°C. (16 mm.) was collected, and on redistillation the fraction b.p. 158 - 160°C. (16 mm.). The yield was 35.2 grams or 28.3%.

(B) 100 Grams of pure 1-methylnaphthalene was mixed with 250 c.c. of carbon tetrachloride in a one litre 3-necked flask. A small amount of iron powder and a few crystals of iodine were added. The solution was cooled to -10°C. by placing the flask in an ice-salt bath. Then, with vigorous mechanical stirring, a solution of 38 c.c. ([12.3 gram] of bromine in 200 c.c. of carbon tetrachloride was slowly added in the absence of direct sunlight. The temperature was kept at -5°C. to -8°C. by varying the rate of addition. The complete addition occupied about two hours. The stirring was continued for a further hour while the temperature was allowed to rise. The solution was then washed free of excess bromine by shaking with 2 N. sodium hydrosulphide solution and then with water. Most of the carbon tetrachloride was distilled off and the residue distilled under reduced pressure. The fraction b.p. 157 - 165°C. (16 mm.) was collected, and on redistillation the fraction b.p. 158 - 160°C. (16 mm.). The yield was 35.2 grams or 28.3%.
chloride was then removed by distillation at atmospheric pressure. The residue was distilled under reduced pressure. The yield of crude 4-bromo-1-methylnaphthalene, b. pt. 179 - 180°C. (27 mm.) was 150.5 grams or 97%. The compound was redistilled and the fraction b. pt 170 - 171°C. (20 mm.) was collected to yield 145 grams or 93%.

4-Bromo-1-bromomethyl-naphthalene

70 Grams of 4-bromo-1-methylnaphthalene in 65 c.c. of carbon tetrachloride was heated under reflux for three hours with 53 grams of N-bromosuccinimide and 0.33 gram of benzoyl peroxide. Another 25 c.c. of carbon tetrachloride was then added and the whole filtered hot from the solid succinimide. (If this operation takes too long some product may begin to separate from the solution.) Carbon tetrachloride was then removed by distillation till only about 30 c.c. of solution remained. On cooling the product separated out. It was then recrystallised twice from petroleum ether (b. pt. 60 - 80°C.) The yield of 4-bromo-1-methylnaphthalene was 71.5 grams (75%), m. pt 102.5°C. (103°C - 104°C.)

4-Bromo-1-Methyl-2-Nitronaphthalene

(A) A mixture of 14.5 c.c. of pure concentrated sulphuric acid and 112 c.c. of pure concentrated nitric acid was placed in a 500 c.c. beaker and cooled to 0°C. in an ice-salt bath. Then, with vigorous mechanical stirring, 100 grams of 4-bromo-1-methylnaphthalene was slowly added from a dropping funnel, while maintaining the temperature below 0°C. After a time a yellow-green viscous substance appeared. This was removed with a glass ladle and washed with water. After the addition of all the 4-bromo-1-methylnaphthalene the solution was stirred for a further few minutes. All the putty was then collected and washed extensively with water.

This material was then extracted with four 250 c.c. batches of boiling petroleum ether (50 - 70°C.) After leaving in a refrigerator for several hours a yellow amorphous substance precipitated above a viscous red material. The
liquid was decanted and the yellow substance collected by the use of a glass ladle. The mother liquor was then used to extract both the original residue and the red material obtained above. The volume of the petroleum ether was kept approximately constant by adding more as required. After six extractions the residue was a red oil and no further amorphous material was recovered. The very crude 1-bromo-2-nitro-1-methylnaphthalene obtained above was purified by fractional recrystallisation from petroleum ether and ethanol. The yield was 15 - 30 grams (see discussion), m. pt. 116 - 117°C. After further purification the melting point rose to 122°C. (121 - 122°C.)

(2) Here the addition was carried out in the reverse order, namely the 1-bromo-1-methylnaphthalene was cooled in a beaker and the nitrating mixture added. Using the quantities above it was found that the addition must be stopped, because of solidification, after only about 70 c.c. of the nitrating solution had been added. The nitration mixture was extracted and purified as above. The yield was 20 - 40 grams.

2-NITRO-1-METHYLNAPHTHALENE

10 Grams of 1-bromo-2-nitro-1-methylnaphthalene,
7.5 grams of cuprous oxide, 5.2 c.c. of acetic anhydride
and 40 c.c. of pyridine were heated together under reflux
for one and a half hours. The mixture was then poured into
500 c.c. of 5% acetic acid. After leaving overnight the
solution was filtered. The solid obtained was extracted
with hot petroleum ether (b. pt. 60 - 80°C.) The extract
was boiled down and filtered. On cooling in the refrigerator
some yellow crystals and a little oil were obtained. After
re-extraction with petroleum ether and then freezing again,
the crystals were collected and then recrystallised twice
from ethanol. The yield was 2.0 gram or 57%, m. pt. 56°C.
(58 - 59°C.)

ETHYL 2-NITRO-1-NAPHTHYLACRYLATE

2.5 Grams of potassium was cut into pieces and added
to 10 c.c. of dry ethanol. 10 c.c. of absolute ether was
added after reaction was complete. The whole was then added with mechanical stirring to 75 c.c. of freshly distilled diethyl oxalate at 0°C. in a beaker. After a quarter of an hour, 11.5 grams of 2-nitro-1-methylnaphthalene was slowly added, with constant stirring, over about half an hour. The solution went deep red after the initial addition. After stirring for a further half an hour the beaker was stoppered and left for twenty four hours in a refrigerator. The solid was then filtered off in a Buchner funnel and washed with a little chilled ethanol and ether and then dried on a vacuum pump. The red solid so obtained was stirred into 250 c.c. of water, acidified with dilute hydrochloric acid, and left for twelve hours. This yielded a light yellow amorphous solid which was filtered off and recrystallised from 500 c.c. of petroleum ether (b. pt. 80 - 160°C.) to give 11 grams of ethyl 2-nitro-1-naphthylpyruvate, a pale lemon crystalline solid, m. pt. 110.5°C.

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<td>N%</td>
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2-NITRO-1-NAPHTHYLPYRUVIC ACID

1 Gram of potassium hydroxide was dissolved by warming in about 30 c.c. of absolute alcohol, and 5 grams of the ester above was added to the warm solution with mechanical stirring. After the red solid initially formed had dissolved, the solution was added to about 500 c.c. of water and left for two hours. The small amount of unchanged ester and dinitronaphthyl-ethane were filtered off and the filtrate acidified with dilute hydrochloric acid. A yellow precipitate of 2-nitro-1-naphthylpyruvic acid formed. This was filtered off and recrystallised twice from 50% alcohol-water. The yield was 3.8 grams or 84%, m. pt. 179°C.

On microanalysis the following figures were obtained:

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OXIDATION OF 2-NITRO-1-NAPHTHYLYSUVIC ACID

3 Grams of the acid was dissolved in a solution of 0.96 grams of sodium hydroxide in 120 c.c. of water. A solution of 2.4 grams of potassium permanganate in 250 c.c. of water was added slowly with vigorous mechanical stirring. The solution was stirred for a further half an hour after the addition was complete.

The solution was then centrifuged and the supernatant liquid collected. The manganese dioxide precipitate was washed with water and again centrifuged. The supernatant liquid was added to that already collected. This was then acidified with dilute hydrochloric acid and extracted with ether. The ethereal layer was then extracted with a saturated solution of sodium bicarbonate. On acidification, this gave about 1.5 grams of a brown solid. This was crude 2-nitro-1-naphthoic acid. The ethereal layer left after extraction with bicarbonate was used to extract the manganese dioxide precipitate obtained by centrifuging. After filtration the excess ether was boiled off and crude 2-nitro-1-naphthaldehyde obtained. This was treated hot with animal charcoal in petroleum ether, filtered and cooled to give the aldehyde. On recrystallisation from methanol yellow needles were obtained, m. pt 119°C. The yield was 0.5 gram (21.5%).

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The aldehyde gives no test with Schiff's reagent in alcohol.

The semicarbazone was produced by dissolving 0.1 gram of the aldehyde in a little alcohol, adding water till just cloudy, and warming for thirty minutes with 0.15 sodium acetate and 0.1 gram semicarbazone hydrochloride. Water was then added and the semicarbazone filtered off and recrystallised from ethanol. The melting point was 279°C. after a transition at ca. 200°C.
The acid was purified as follows:— The crude acid was dissolved in 20 c.c. of alcohol and heated under reflux for four hours while a stream of hydrogen chloride gas was directed on its surface. After treatment with animal charcoal and filtration some of the alcohol was distilled off. Excess water was then added and the solution extracted with ether. Extraction with saturated sodium bicarbonate solution and subsequent acidification with dilute hydrochloric acid yielded about 1.0 gram of still impure acid, m. p. 187 – 195°C. Careful extraction with dilute (30%) ethanol eliminated the main impurity, a red substance, and on repeating the extraction, followed by two recrystallisations from dilute ethanol, pure 2-nitro-1-naphthoic acid was obtained as pale yellow crystals, m. p. 202°C. The yield was ca. 0.6 grams (24%).

On microanalysis the following figures were obtained:—

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<th></th>
<th>C%</th>
<th>H%</th>
<th>N%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcd from formula</td>
<td>60.61</td>
<td>3.25</td>
<td>6.45</td>
</tr>
<tr>
<td>Microanalysis</td>
<td>61.04</td>
<td>3.30</td>
<td>6.34</td>
</tr>
</tbody>
</table>

Oxidation of 2-Nitro-1-Naphthaldehyde

0.3 Gram of the aldehyde was dissolved in 50 c.c. of acetone and 0.15 grams of potassium permanganate was dissolved in 20 c.c. of water and added, drop by drop, to the above solution with vigorous mechanical stirring. After an interval the production of brown manganese dioxide became apparent. Stirring was continued for two hours and then the precipitate was filtered off in a Hirsch funnel and washed with acetone till the washings were colourless. The combined acetone-water filtrate was evaporated down to remove the acetone. The aqueous remnant was extracted with ether which was in turn extracted with saturated sodium bicarbonate solution. The ethereal layer contained unchanged 2-nitro-1-naphthaldehyde which was recovered.

On acidification of the bicarbonate solution 0.15 gram of
greenish yellow 2-nitro-1-naphthoic acid was obtained, m. pt. 198 - 200°C.

**2,2'-DINITRONAPHTHYL-1:1'-ETHANE**

0.75 grams of sodium was dissolved in 20 c.c. of ethanol in a small flask. After cooling in an ice bath, 2 c.c. of diethyl oxalate was slowly added. Then 3 grams of 2-nitro-1-methylnaphthalene was added and the whole boiled under reflux for twenty minutes. The solution was then added to 100 c.c. of water and a few drops of dilute sodium hydroxide solution added to ensure that all acidic material was dissolved. The brown precipitate was filtered off in a Buchner funnel. It was washed with hot ethanol, dissolved in hot chlorobenzene, treated with animal charcoal, filtered and on cooling ca. 1.5 grams of 2,2'-dinitronaphthyl-1:1'-ethane was obtained. On recrystallisation from chlorobenzene, bright yellow flakes were obtained, m. pt. 232°C.

On microanalysis the following figures were obtained:

<table>
<thead>
<tr>
<th></th>
<th>Ca</th>
<th>H</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calculated from formula</td>
<td>70.93</td>
<td>4.53</td>
<td>7.52</td>
</tr>
<tr>
<td>Microanalysis</td>
<td>70.90</td>
<td>4.47</td>
<td>7.49</td>
</tr>
</tbody>
</table>
(3) EXPERIMENTAL SECTION

(1) Preparation of Ester

Neither 8-nitro-1-naphthoic acid nor 2-nitro-1-naphthoic acid can be esterified by the Fischer-Espies method. \(^4\) Kast and \(^5\) produced the ethyl ester of the former by the reaction of its silver salt with ethyl iodide. This method also proved applicable to the esterification of 2-nitro-1-naphthoic acid.

**ETHYL 8-NITRO-1-NAPHTHOIC ACID**

10 Grams of twice recrystallised 8-nitro-1-naphthoic acid, m. pt. 220°C., was dissolved in the minimum quantity of 3N ammonium hydroxide solution. 6 Grams (ca. 20% above theoretical) of silver nitrate, in 20 c.c. distilled water, was added and the resultant yellow precipitate of the silver salt filtered off in a Buchner funnel. After washing the precipitate with water and a small amount of ethanol, it was dried in a vacuum desiccator. The yield was almost quantitative. (By acidification of the aqueous residues and subsequent extraction with ether a very small amount of the acid can be recovered.)

5 Grams of the above silver salt was heated under reflux for ten hours with 30 c.c. of freshly distilled ethyl iodide. The excess ethyl iodide was then removed by distillation under reduced pressure at 30°C. The solid material remaining was extracted with ether to separate the ethyl 8-nitro-1-naphthoate from the silver iodide. After washing with aqueous bicarbonate solution and with water, the ether was boiled off to give the crude ester. After two recrystallisations from ethanol, very pale yellow crystals were obtained, m. pt. 66°C. The yield was 2.8 grams (75%). As this compound was required in high purity for kinetic work it was recrystallised twice more from ethanol and was then dried by heating in a vacuum oven for twelve hours at 50°C.

**ETHYL 2-NITRO-1-NAPHTHOIC ACID**

By an analogous procedure to that described above 0.6 grams of 2-nitro-1-naphthoic acid was converted to a
yellow-gold silver salt. This was heated under reflux for ten hours with 12 c.c. of ethyl iodide. After extraction as above and two recrystallisations from 70% ethanol-water, pale yellow crystals were obtained m. pt. 92°C. The yield was 0.47 grams (75% overall).

In a second preparation involving 0.3 grams of the acid the silver salt formed was heated under reflux with 15 c.c. of ethyl iodide. A yield of 85% of the ester was obtained after purification as above. On microanalysis the following figures were obtained:

<table>
<thead>
<tr>
<th></th>
<th>C%</th>
<th>H%</th>
<th>N%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calculated from formula</td>
<td>63.61</td>
<td>4.52</td>
<td>5.72</td>
</tr>
<tr>
<td>Microanalysis</td>
<td>63.43</td>
<td>4.78</td>
<td>5.20, 5.76</td>
</tr>
</tbody>
</table>

(The original figure of 6.20% for the percentage of nitrogen was unsatisfactory and was probably caused by the presence of some ethyl nitrate, produced from silver nitrate and ethyl iodide. The impurity was removed on further purification.)

Prior to its use in kinetic work the ethyl 2-nitro-1-naphthoate was again recrystallised from aqueous ethanol and then dried for twelve hours in a vacuum oven at 50°C.

An attempt was also made to esterify 8-nitro-1-naphthoic acid with ethanol by employing trifluoroacetic anhydride as a catalyst. This reagent has proved suitable as a catalyst in the esterification of polysaccharides where it enables the reaction to be conducted under sufficiently mild conditions to avoid a breakdown in the polysaccharide molecule. It has been postulated that it acts by reacting with the carboxylic acid to release a -OH ion which reacts further with the alcohol to yield an ester. It was thus possible that under stringent conditions it might cause the esterification of 8-nitro-1-naphthoic acid.

Trifluoroacetic anhydride was prepared by boiling 10 grams of trifluoroacetic acid under reflux for fifteen minutes with 9 grams of phosphorus pentoxide. On distillation the fraction 35.5° - 41°C (750 mm.) was collected. The yield was 6.55 grams (62%) of a colourless liquid.
Stacey reported b. pt. 39°C. Yield 74%.

1.5 Grams of 8-nitro-1-naphthoic acid and 1 gram of trifluorocessetic anhydride were heated to 60°C. in a water bath and kept at this temperature under reflux for thirty minutes. Then 0.2 c.c. of ethanol was added and the whole boiled under reflux for ninety minutes. Another 0.2 c.c. of ethanol was then added and the reflux continued for a further sixty minutes. The reaction mixture was then added to 50 c.c. of saturated sodium bicarbonate solution. This was extracted with ether and the ethereal layer washed with water and then dried. The ether was distilled off to leave a light yellow material which was recrystallised twice from ethanol, m. pt. 167°C. On microanalysis the following figures were obtained:

<table>
<thead>
<tr>
<th>C</th>
<th>H</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>66.72</td>
<td>2.61</td>
<td>7.75</td>
</tr>
</tbody>
</table>

No obvious structure can be postulated to fit these figures.

(II) Preparation of Reagents

Volumetric Ware was calibrated using methods given by Vogel. These consist of determining the weight of water occupied by the volume which is to be calibrated, and then calculating the true volume from the weight of water and its density at the calibration temperature. All weighings were corrected to "in vacuo".

The water used for making up solutions was from the laboratory distilled-water supply. As the accuracy of the method of analysis is independent of the conductance of the solvent, the conductivity of the water was not critical. Where necessary the water was freed from carbon dioxide by boiling it under reduced pressure for about fifteen minutes at 40°C. It was then saturated with nitrogen, cooled and used immediately for the purpose required.

Ethanol used in the solvent mixture for hydrolysis runs was obtained by purifying commercial "absolute alcohol".

The main impurities are aldehydes and other alcohols. The amine and other basic impurities were first removed by dia-
tilling the ethanol from a mixture of 5 c.c. of concentrated sulphuric acid and 40 c.c. of water per litre. The aldehyde were then removed by a modification of the method of Dunlap. This consists of producing finely divided silver oxide in the alcohol by adding potassium hydroxide solution to ethanol containing silver nitrate. The silver oxide so produced oxidized the aldehydes to the respective acids.

2 Grams of silver nitrate in 4 c.c. of water was added per litre to the alcohol, in 4 litre batches. Then a solution of 1.5 grams of potassium hydroxide in 7.5 c.c. of water per litre (50% theoretical) was added in aliquots over three days. Each addition was made slowly from a pipette to avoid coagulation of the silver oxide formed. After four days the mixture was filtered and then distilled. This precipitation process was repeated ten times. The ethanol thus obtained was distilled through a 4.5 foot column packed with Dixon gauze rings, a continuous current of hydrogen being passed through the apparatus at the same time. A distillation-head with a liquid trap of 150 c.c. capacity was employed. The first 150 c.c. of distillate were thus collected here and the column then ran at total reflux unless a collection vessel was attached and the appropriate stopcock opened. The design of the head allowed for the enrichment of the trapped liquid in the lower boiling fractions of the distillate. 4.5 Litre batches were distilled at a time and the procedure employed was to allow the column to run for twenty four hours under total reflux, remove the 150 c.c. of trapped liquid, then run for a further twelve hours under total reflux and again remove the 150 c.c. of trapped liquid. Most of the aldehyde present should be present in these initial fractions. The next 3.25 litres of distillate was collected over thirty six hours. Finally the alcohol was redistilled again through the column, the 150 c.c. of liquid collected after twenty four hours of total reflux being rejected. 3.5 Litres was then collected per 4.5 litre batch.

The density of the sample was determined by means of
a calibrated pycnometer at 25.00°C. The composition was found by interpolating the density-composition data for ethanol-water mixtures from the International Critical Tables. An estimate of the amount of aldehyde still remaining in the sample was made by a comparative test with Schiff’s reagent. Equal volumes of standard aldehyde-water solutions were made up in test tubes and the same volume of the purified ethanol placed in another. An equal amount of Schiff’s reagent was then added to each and they were compared colourimetrically by viewing each through a longitudinal axis. The aldehyde present in the purified alcohol was thus shown to be less than 0.005%.

Sodium hydroxide solution, the reagent used for the hydrolysis of the esters, was prepared from the Analar material made carbonate free by centrifuging a saturated aqueous solution, in which the carbonate is insoluble. After dilution with carbon-dioxide free distilled water, to approximately the normalities required, the solutions were stored in polyethylene bottles fitted with a siphon, made of polyethylene tubing, and a stopcock and a soda-lime guard tube. The small amount of solution entrapped in the glass stopcock was run off each time before use.

The solutions were standardised against Analar potassium hydrogen phthalate using phenolphthalein as an indicator.

Standard Ester Solutions, where required, were made by dissolving a weighed amount of the ester in a weighed amount of the purified ethanol. From the molarity of the sodium hydroxide solution and the composition of the ethanol, the required molarity of the ester solution, to make the reaction solution equimolar in ester and alkali and 85% ethanol 15% water by weight, was calculated exactly. About 80 to 100 c.c. of ethanol was weighed out exactly and the weight of ester to be added calculated. This was weighed out exactly into a small glass vessel and then added to the alcohol.

Ethyl-l-Mandelate. This was redistilled twice under
reduced pressure and the middle fraction of the distillate, b. pt. 170 - 172°C, (15 mm.) was collected. It was dried in a vacuum oven for twelve hours at 60°C.

**Conductivity Bridge**

The hydrolysis of the esters was followed by measuring the change in resistance of the system by means of a conductivity bridge. The bridge used was similar to that described in detail by Fischer. It consisted essentially of, (i) a regulated power supply, (ii) a Wien bridge type oscillator producing a current of frequency approximately 1 kilocycle per second, (iii) the wheatstone bridge, (iv) a high grade amplifier with associated T networks so that the output had, as nearly as possible, a pure frequency of approximately 1 kilocycle per second, and (v) a detector unit into which two detectors were incorporated. For the initial balance a cathode follower and a rectifier converted the amplified bridge signal into a direct current which was detected by a 50/0/50 microammeter. At impedance balance there was no bridge signal and consequently the microammeter showed zero current. As the bridge went through balance the microammeter went through a minimum deflection at the zero. The second detector was more sensitive and was used to obtain a final resistance balance after the coarse detector indicated impedance balance. This second detector was phase sensitive and was activated by the phase change as the bridge went through balance. As the resistance of the ester solution rose through the balance the microammeter needle moved from the negative to the positive side of the scale. As it passed through zero the balance point was reached. Either one or other of these two detectors could be brought into circuit by means of a double-pole double-throw switch.

Some modifications were made by Scott to the bridge circuit described by Fischer to eliminate the faults he described, namely flickering of the microammeter needle.
and a periodic variation of the stability of the bridge. In the bridge used a faulty potentiometer, which was used to control the gain for the microammeter, was found to be one reason for the former fault. A more important error was regeneration of current by the detector circuit from the bridge supply circuit. Scott modified the circuit by putting the bridge supply circuit on a separate transformer. He also found that the amplifier was very sensitive to pick-up in the circuit used and modified the circuit accordingly.

The method of measurement of resistance was to connect the cell to the appropriate terminal on the bridge and to connect a resistance box in the other arm of the bridge. Using the coarse balance the microammeter needle was brought to a minimum value by alternately adjusting resistance and capacitance while slowly increasing the gain. When the gain was on full and the needle on the minimum value possible the bridge was switched on to the "fine balance" and the final adjustment made to the resistance. (It was found that the change in capacitance balance was insignificant for a small change in resistance.) The resistance could thus be obtained to the nearest 0.01 ohm, if necessary.

When the bridge was run in conjunction with a cathode-ray oscillograph, acting as a detector, it was found that significant rectification took place in the cells employed for the ester hydrolysis. This showed up as a harmonic in the wave form on the detector. On balancing the bridge as described above the primary wave was slowly reduced and the secondary wave became more important and eventually the state was reached where the unbalanced portion of impedance was due to this secondary effect. Switching on to fine balance thus led to an erroneous balance. This situation was eliminated by incorporating a ferrous oxide coil with a rejection of 2 kilocycles per second in the detector circuit and thus effecting a 25:1 reduction in the secondary current. The cathode-ray oscillograph was also used to adjust the bridge to give as pure a wave form as possible.
P.V.C. Shielded Copper Leads

B.14 Cores.
(Caps made from B.14 sockets)

Filling tubes for compartments

COMPARTMENT B
(capacity ca. 3 cc.)

glass shielding tubes,
wick filled. The copper
leads are soldered to platinum
wires connected to the electrodes.

COMPARTMENT A
(capacity ca. 1cc.)

Fig. 5
The oscillator output of the bridge was adjusted to about 0.05 volt. This was sufficient to enable readings to be taken to the accuracy required and it avoided polarization that was shown to take place when much higher values were employed.

Conductivity Cells used were of the type employed by Fischer and are shown and described in Fig. (5). The electrodes were made of bright platinum and were about 0.5 cm. square and 2 cm. apart. The resistance of the cells under working conditions varied from 300 to 800 ohms depending on the alkali concentration and temperature used. Shedlovsky recommends a value of not less than 1000 ohms in order to avoid high current densities and consequent polarization. However, as the bridge output was only 0.05 volt and the cells were only switched into the circuit for very brief periods at a time, the error caused by polarization is likely to be very small. A Leeds and Northrup double-pole double-throw switch was used to bring the cell into circuit with the bridge when the resistance of the cell was to be measured.

The resistance used in the measuring arm of the bridge was a Sullivan and Griffiths decade type resistance box (No. 5248/1955) of 0.05% accuracy, and incorporating steps of 0.01 to 1000 ohms. The leads from the cells to the double-pole switch were kept as short as possible and all other leads were made of shielded cable.

The thermostatted bath used was waterfilled and the temperature was controlled by a mercury-toluene regulator in series with a Sunvic hot wire vacuum switch, a simmerstat and a heating coil. A second heating coil was controlled by a variac. By appropriate adjustment of the simmerstat and the variac the temperature was kept constant to ± 0.01°C. Timing was done by a stopwatch previously checked against the N.Z.R.S. time signals. Its variation was found to be negligible.
(IV) Procedures for following kinetics

It was found that the slow rates of hydrolysis exhibited by ethyl 1-naphthoate, ethyl 2-nitro-1-naphthoate and ethyl 3-nitro-1-naphthoate made their measurement by a conductivity method difficult. Modifications had to be made in the procedure used by Fischer (designated as procedure (a) below) to measure the rates of hydrolysis of ethyl 3- and ethyl 4-nitro-1-naphthoates.

Procedure (a). Compartment A (see Fig. 5) of a clean, dry cell was filled with 5 to 10 grams of standard ester solution by means of a weight burette. From the weight taken, the required volume of sodium hydroxide was calculated and this volume was loaded into compartment B by means of a calibrated 1 ml burette. The ground-glass caps were then greased, fitted into place and held there by rubber bands. The cell was immersed in the thermostatted bath taking care not to mix the two solutions. After allowing about thirty minutes for the cell contents to reach the bath temperature the two solutions were thoroughly mixed, the stopwatch started and the solution collected in compartment A. A further thirty to forty-five minutes was allowed to elapse before any measurement of resistance was made. Then 30 measurements of resistance were made over a period of about three hours. In general two cells were in the thermostatted bath concurrently and a double-pole double-throw switch was used to bring each into circuit with the bridge as required. The following method was used to obtain each measurement of resistance after the cell had been brought into circuit with the bridge. A rough value of the resistance of the cell was first obtained using the coarse balance and the method described on page 46. Then, with the gain on full, a value of resistance slightly above that of the cell was set on the resistance box in the measuring arm. As the needle moved towards a minimum value the capacitance was constantly adjusted. When the value on the micromenueter had fallen to about 1 microamp the "fine balance" was switched
on and the time taken as the needle crossed the zero reading on the scale. The "fine balance" was then switched off, the gain returned to zero and the circuit with the cell broken. The measurement of time was always taken to the nearest second.

The thirty measurements were arranged into three consecutive groups of ten thus:

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_{11}, t_{11}$</td>
<td>$R_{12}, t_{12}$</td>
<td>$R_{21}, t_{21}$</td>
</tr>
<tr>
<td>$R_{12}, t_{12}$</td>
<td>$R_{13}, t_{13}$</td>
<td>$R_{22}, t_{22}$</td>
</tr>
<tr>
<td>$R_{13}, t_{13}$</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>$R_{14}, t_{14}$</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>$R_{15}, t_{15}$</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>$R_{16}, t_{16}$</td>
<td>$R_{26}, t_{26}$</td>
<td>$R_{30}, t_{30}$</td>
</tr>
</tbody>
</table>

and ten values of $A_{eq}$, (where $A_0$ is the initial concentration of either reactant and $k$ is the rate constant), were obtained, one from each group of three, by employing the formula:

$$A_{eq} = \frac{2^{R_{AB}(t_B-t_A)}}{R_{AB}(t_B-t_A)}$$

In the runs done by Fischer on ethyl 3- and ethyl 4-nitro-1-naphthoates the ten values of $A_{eq}$ so obtained showed a purely random distribution of values and, in general, lay within a range of about 5%. However when runs were performed on ethyl 1-naphthoate at 30°C, and 40°C, the values obtained from most runs showed a marked and systematic trend. The following ten values of $A_{eq}$ were obtained from a run on ethyl 1-naphthoate at 40°C, with $A_0$ equal to 0.104 moles litre$^{-1}$.

$A_{eq} \times 10^4 = 1.627, 1.602, 1.563, 1.519, 1.483, 1.451, 1.412,$

$1.388, 1.370, 1.342.$

This anomaly was more apparent at 40°C than at 30°C.

Wilson gives a figure of $1.6 \times 10^3$ litre mole$^{-1}$ sec$^{-1}$ for the rate constant of ethyl 1-naphthoate at 40°C, and thus the initial values obtained appeared to be the closest to the value expected. This was typical of the runs that showed the trend described above. At 50°C, a lower value of $A_0$ was
used (ca. 0.64 moles litre\(^{-1}\)) but this made the trend more marked and no significant value could be derived for a rate constant.

The only obvious differences between this work and that of Fischer were, (i) the smaller rates of hydrolysis, (ii) the higher concentrations of alkali used and (iii) the lower values of cell resistance employed. In order to ascertain if any significant polarisation took place a "blank" run was conducted exactly as a normal run except that an ethanol-water mixture was added to compartment A (Fig. 5) of the cell instead of the ester solution. A significant and steady change of resistance was found to take place even if the resistance measurements were made at infrequent intervals. By measuring the resistance changes of a series of these "blank" runs it was found that the percentage change in resistance with time was increased both by an increase in temperature and by a decrease in alkali concentration. The value of the potential drop across the electrodes had originally been about 1.0 volts but it was found that this did lead to some polarisation as evidenced by a concurrent rise in both the resistance and capacitance of a "blank" run when the bridge was left in circuit with the cell. On reducing the value of the bridge output to 0.05 volts the change in a "blank" run became almost independent of whether the bridge and the cell were left in circuit between measurements or not, and the capacitance of the cell system decreased as the resistance rose. The reason for this rise in resistance would thus appear to be explicable in terms of a chemical reaction involving the reaction of the highly conducting hydroxyl ions rather than an electrical effect. The cells used were cleaned with organic solvents, chromic acid and an alkaline-phosphate cleaning mixture without significantly decreasing the rate of change of the resistance in a "blank" run. Wilson found that in a blank run performed by a titration method there was a decline in the hydroxyl ion concentration if the alcohol used was not
caredly purified. The main impurity likely to remain in
the purified ethanol used would be aldehydes and, in fact,
when a very small quantity of acetaldehyde to a "blank" run there did appear to be an increase in the rate of change
of resistance. However it is difficult to visualise a
reaction involving acetaldehyde that could lead to a de-
crease in the concentration of the alkali and, furthermore,
a "blank" run performed using commercial alcohol was of the
same order as the "blank" runs involving purified alcohol.
A more likely reason for the rise in resistance is alkali
attack on the pyrex glass of which the cell was construc-
ted. An examination of the figures quoted for the rate
of attack of alkali on pyrex glass and a computation of the
likely effect on the resistance of the cell revealed that
such an assumption was not inconsistent with the changes
actually observed. Attempts made to provide the inner
walls of the cell with a coating of silicones or polyethylene
met with no success as, at the temperatures used, the
alcohol/alkali mixture appeared to attack the coatings.
A cell of a material like teflon, which is remarkably
resistant to attack by both alkali and alcohol, would be
suitable for an examination of this problem but unfortunately
it is difficult to fabricate and is not readily available.

While the rate of hydrolysis of the ester increases
with increase in concentration of the alkali, it was found
that the percentage change in the resistance of a cell over
a fixed time during a "blank" run fell on increasing the
alkali concentration. Thus as the value of Ao used was
raised the effect of changes in resistance caused by effects
other than ester hydrolysis became less important. Unfortu-
nately the value of Ao has an upper limit determined both
by the solubility of the ester in 85% ethanol-water and by
the difficulties inherent in measuring the resistance of a
cell of high conductance. However it was obvious that a
satisfactory determination of the rate constant for ethyl
1-naphthoate should be obtainable at 50°C, by using a value
of A0 equal to that used at lower temperatures. In order to measure the changes in resistance caused by effects other than ester hydrolysis the procedure was modified as below. This procedure is also preferable to procedure (a) as the ester required is weighed out and added to each run separately, thus eliminating errors caused by the evaporation of ethanol from standard ester solutions.

Procedure (b). Nine to ten grams of the purified ethanol was loaded into compartment A (Fig. 5) of a clean, dry cell. The calculated volume of aqueous alkali to produce an 85% ethanol-water solution was then added and the cell well shaken. The cell was immersed in the thermostatted bath and allowed to come to temperature equilibrium over a period of thirty minutes. Measurements of the resistance of the cell were then taken over a short period of time to ensure that changes in resistance caused by effects other than ester hydrolysis were likely to be small compared to resistance changes caused by the latter. The calculated amount of ester, to make the solution equimolar in ester and alkali, was weighed out into a glass capsule and this was added to compartment B of the cell. The cell contents were then thoroughly mixed and the stopwatch started, taking care to avoid the capsule entering compartment A in order to prevent damage to the electrodes. After descending all the solution into compartment A the cell was left in the bath for thirty to forty minutes before resistance measurements were commenced. Thirty measurements of resistance were then made as described under Procedure (a) and ten values of A0k computed. Three runs were performed on ethyl L-naphthoate, at 50°C, in this manner and while two each gave ten random values of A0k, the other one showed a trend of the type already described.

An attempt was made to apply this procedure to the determination of the rate constant of ethyl L-nitro-L-naphthoate at 50°C. However its rate of hydrolysis at this temperature was such that the consequent change in resistance was only of the order of that changed by a "blank"
run, and it was impossible to calculate a rate constant by the method above. Procedure (c) was evolved to enable rate constants to be determined by conductivity methods in cases where the rate constant is less than $10^{-3}$ litre mole$^{-1}$ sec$^{-1}$.

**Procedure (c).** It was shown (see Appendix B), that

$$k = \frac{1}{A\sigma R_0} \times \frac{R_\infty}{R_\infty - R_p} P$$

where $P$ is the gradient of a graph of resistance against time, for a run, at the point where the resistance is $R_p$, $R_0$ is the resistance when $t = t_0$ and $R_\infty$ is the resistance when all the ester has been hydrolysed.

The ethanol and the calculated quantity of alkali were mixed in the cell as described in procedure (b) above and the cell immersed in the thermostatted bath. After allowing the cell contents to reach temperature equilibrium with the bath about eight measurements of the resistance of the cell were taken over a period of one hour, and the resistance plotted on a graph against time. The calculated quantity of ester was then added and the cell contents mixed as above and the stopwatch started. Two initial measurements of resistance were taken, one thirty minutes and the other sixty minutes after mixing. Ten values of the resistance of the cell were taken over an hour commencing about two hours after the cell contents were mixed. These values were also plotted on a graph against time and the gradient at the centre point ascertained. The value of this gradient, in ohms per second, was then corrected by subtracting the corresponding value for the initial "blank" run. This corrected value was taken as $P$. $R_0$ was calculated by extrapolating the $R/T$ plot to $t = t_0$, making use of the two initial values of resistance measured. $R_\infty$ was determined by measuring the resistance of a cell made up to be equivalent to that expected after complete hydrolysis, namely a cell containing ethanol and alkali as above but with an equivalent quantity of the appropriate carboxylic acid added instead of its ethyl ester. Two small corrections
were made in order to refine procedure (c), (i) the amount of ester added was slightly less than the calculated quantity by an amount roughly equivalent to the alkali consumed before the ester was added, as calculated by the rise in resistance of the cell and (ii) the value of Rp was corrected for the change caused by the factors other than ester hydrolysis. Using the procedure above a value was obtained for \( k(30^\circ C) \) for ethyl 1-naphthoate which was within 2% of that given by Wilson.  

At the end of each run the ester was immediately recovered by acidifying the cell contents, adding a large excess of water and then extracting with ether. The ethereal extract was washed with aqueous bicarbonate solution, to remove the carboxylic acid, and then the ether evaporated and the ester so obtained recrystallised from ethanol.

A typical run is illustrated below.

### Run 49

**Ethyl 6-nitro-1-naphthoate**

**PROC.**

"Blank" run - see graph in Fig. 5

Hydrolysis run - see graph in Fig. 7

\( Rp = 305 \text{ ohms} \)

\( Rc = 293 \text{ ohms} \)

\( R = 657 \text{ ohms} \)

\( Ac = 0.0969 \text{ moles litre}^{-1} \)

\( P = 2.30 \text{ ohms hour}^{-1} \)

\[
k = \frac{1}{0.0969} \times \frac{1}{293} \times \frac{2.30}{3600} \times 657
\]

\[
= 3.85 \times 10^{-5} \text{ litre mole}^{-1} \text{ sec}^{-1}
\]
**Run 49**

A "Blank"

![Graph](Fig. 6)

B Run

![Graph](Fig. 7)
The results for runs with the conductivity bridge are listed below. The only runs neglected were those performed on ethyl 1-naphthoate at 50°C, by procedure (a), where no rate constant could be calculated, and two runs performed on ethyl 2-nitro-1-naphthoate where the change in resistance of the "blank" run was too random to enable a satisfactory gradient to be calculated. The rate constant, in litre mole⁻¹ sec⁻¹, is listed for each run. (I) = ethyl 1-naphthoate, (II) = ethyl 2-nitro-1-naphthoate, (III) = ethyl 5-nitro-1-naphthoate.

<table>
<thead>
<tr>
<th>Temperature °C</th>
<th>(I) $(\times 10^3)$</th>
<th>(II) $(\times 10^4)$</th>
<th>(III) $(\times 10^5)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>30.00 ± 0.02</td>
<td>0.575</td>
<td>0.520</td>
<td>0.622</td>
</tr>
<tr>
<td></td>
<td>0.649</td>
<td>0.658</td>
<td>0.678</td>
</tr>
<tr>
<td>mean</td>
<td>0.63</td>
<td></td>
<td></td>
</tr>
<tr>
<td>40.00 ± 0.02</td>
<td>1.50 ± 1.35</td>
<td>1.50 ± 1.40</td>
<td>1.61 ± 1.35</td>
</tr>
<tr>
<td>mean</td>
<td>1.61 ± 1.35</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50.00 ± 0.02</td>
<td>3.48 ± 3.12</td>
<td>3.30</td>
<td>2.53</td>
</tr>
<tr>
<td></td>
<td>3.46</td>
<td>3.34</td>
<td>2.57</td>
</tr>
<tr>
<td></td>
<td>3.48</td>
<td></td>
<td>2.59</td>
</tr>
<tr>
<td>mean</td>
<td>3.46</td>
<td>3.32 ± 2.56</td>
<td></td>
</tr>
<tr>
<td>55.00 ± 0.02</td>
<td>4.26</td>
<td>3.85</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4.58</td>
<td>4.25</td>
<td></td>
</tr>
<tr>
<td>mean</td>
<td>4.42 ± 0.07</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
\[
\begin{array}{ccc}
(1) & (11) & (111) \\
\times 10^3 & \times 10^4 & \times 10^5 \\
60.00 \pm 0.02 & 6.07 & 6.24 \\
 & 6.45 & 6.74 \\
 & 6.48 & 6.92 \\
 & 7.30 & \\
\text{mean} & 6.54 & 6.60 \\
65.00 \pm 0.02 & 10.1 & 9.36 \\
 & 10.9 & 10.10 \\
\text{mean} & 10.55 & 9.73 \\
\end{array}
\]

The results for each compound were fitted to an equation of the form

\[
\ln k = D - \frac{E}{RT}
\]

where \(k\) is the rate constant, \(D\) and \(E\) are constants, \(R\) the gas constant per mole and \(T\) the absolute temperature.

In the exponential form this is known as the Arrhenius equation:

\[
k = Ae^{-\frac{E}{RT}}
\]

where \(D = \ln A\)

The plot of \(-\log k\) against \(T^{-1}\) for ethyl 2-nitro-1-naphthoate is shown on page 59, and that for ethyl 8-nitro-1-naphthoate on page 60. The points shown are those for the mean values of the rate constants at the given temperatures but the lines shown were fitted to the actual individual values for each run by the least squares method.

\[
\begin{array}{ccc}
\text{x (cal./g.mole)} & \log_{10}A \\
\text{Ethyl 2-nitro-1-naphthoate} & 16.62 \pm 0.75 & 7.67 \pm 0.49 \\
\text{Ethyl 8-nitro-1-naphthoate} & 15.71 \pm 0.36 & 6.66 \pm 0.27 \\
\end{array}
\]
ARRHENIUS PLOT
ETHYL 2-NITRO-1-NAPHTHOATE
ARRHENIUS PLOT

ETHYL 8-NITRO-1-NAPHTHOATE

\( \frac{\text{NO}_3^3}{T} \)

\(-\log_{10} k\)

4.0 4.2 4.4 4.6
Prior to discussing the actual results obtained, it is useful to consider the accuracy and applicability of the methods employed to obtain them.

The conductivity method for following the ester hydrolysis was chosen in preference to a titration method, such as that of Wilson, for two reasons. Firstly, as only about 10% of the amount of ester is required per run, the conductivity method simplifies the synthetic problems involved in the preparation of the esters. This advantage is of primary importance for ethyl 2-nitro-1-naphthoate on account of the difficulties inherent in its preparation. Secondly, the conductivity method is much more sensitive to changes in hydroxide ion concentration than is the titration method. Thus one can measure low rates of hydrolysis in shorter periods of time by the former method. Fischer considered that the precision of a series of runs measured by the conductivity method he employed, designated procedure (a) in this work, was of the same order as that which would be obtained by a titration method.

The discovery that the resistance of a cell containing an alkaline 65% aqueous ethanol solution changed considerably over a period of time severely limits the applicability of procedure (a). Unless the changes in resistance caused by reasons other than ester hydrolysis are negligible compared to those caused by it, erroneous results will be obtained. This is especially true because the equation used to calculate the rate constant is very sensitive to variations in resistance and time.

Procedure (b) employed in this work enables an estimation of this error to be made in any particular run. It can, however, be stated that the procedure is unsuitable for esters having a rate constant for alkaline hydrolysis smaller than $5 \times 10^{-3}$ litre mole$^{-1}$ sec$^{-1}$. 
Procedure (c) is suitable for the measurement of hydrolysis of esters having small rate constants. Its accuracy is limited by the unverified assumption that the change in resistance caused by effects other than ester hydrolysis is unchanged on the addition of the ester. As it would be expected that such effects would change as the concentration of base present falls during hydrolysis, it is necessary that measurements are taken only over the initial stages of ester hydrolysis. When the results obtained are considered by standard statistical procedures, it is found that the differences between any two runs at one temperature are often not explicable on statistical grounds alone. While individual runs may not give rate constants of high accuracy, the method gives figures that enable activation energy and entropy values to be calculated to a satisfactory degree of accuracy.

The only obvious alternative to the method above, in the case of esters with small rate constants, would be their hydrolysis in sealed tubes at elevated temperatures. Goeing, Rubin and Newman, for instance, used such a method to determine the rate constants for the alkaline hydrolysis of a series of substituted 2,6-dimethyl-benzoates. However, about 15 to 20 grams of each ester would be required and, with ethyl 2-nitro-1-naphthoate, the preparation of such quantities is impracticable.

The Mechanism of the Reaction. Ingold has classified the possible mechanisms of ester hydrolysis. His classification is based on, (i) the nature of the reagent, either acidic (A) or basic (B), (ii) the position of rupture of the ester, namely whether acyl-oxygen (AC) or alkyl-oxygen (AL) fission occurs and (iii) the order of the reaction, either unimolecular (1) or bimolecular (2). Thus there are four possible mechanisms for alkaline ester hydrolysis and these can be designated B\textsubscript{AL}^1, B\textsubscript{AL}^2, B\textsubscript{AC}^1 and B\textsubscript{AC}^2. The mechanism B\textsubscript{AC}^1 has not been observed. The expected mechanism for the alkaline hydrolysis of ethyl 2-
ethyl 8-nitro-1-naphthoates is either $B_{AC}O^2$ or $B_{AL}O^2$. The mechanism $B_{AC}O^2$ can be represented in two ways. Either as a carbonyl addition and its retrogression, as follows,

$$
\text{HO}^+ + \text{C} = \text{OR} \quad \text{slow} \quad \text{HO}^+ \quad \text{fast} \quad \text{HO}^+ \quad \text{C} + \text{OR} \quad (B_{AC}O^2)
$$

or as a nucleophilic substitution:

$$
\text{HO}^+ + \text{C} = \text{OR} \quad \text{slow} \quad \text{HO}^+ \quad \text{C} \quad \text{OR} \quad \text{fast} \quad \text{HO}^+ \quad \text{C} + \text{OR} \quad (B_{AC}O^2)
$$

In each case the alkoxide ion subsequently removes a proton from the acid molecule:

$$
\text{R'}\text{CO}_2\text{OH} + \text{OR} \quad \text{fast} \quad \text{R'}\text{CO}_2\text{O}^+ + \text{HOR}
$$

The actual intermediate complex will be mesomeric between the two structures shown above and therefore more stable than either. It has been established that the intermediate is a molecule. In the case where $\text{R'}$ is aromatic, it has been found that substituents in the ring exert a marked effect on the rate. Substituents in meta or para positions that exert $-I$, $-M$ effects accelerate the reaction while those exerting $+I$, $+M$ effects retard it. With the exception of fluorine, ortho substituents retard more, or accelerate less, than the corresponding para substituents. This is assumed to be caused by the superposition of a steric retardation on the polar effect of all bar the smallest ortho substituent.

The mechanism $B_{AL}O^2$ can be similarly formulated

$$
\text{HO}^+ + \text{CH}_2\text{O} = \text{C} - \text{R'} \quad \text{fast} \quad \text{HO}^+ \quad \text{CH}_2\text{O} = \text{C} - \text{R'} \quad (B_{AL}O^2)
$$

Polar and steric effects can be predicted. In particular, if $\text{R'}$ is aromatic, substituents in it that exert $-I$, $-M$ effects would accelerate the reaction while those exerting $+I$, $+M$ effects would retard it, but these effects would be less marked than in mechanism $B_{AC}O^2$. If $\text{R''}$ is a group exerting a $+I$ effect, it will retard the reaction.
The generality of mechanism \( B_{AL}^2 \) in principle, despite its usual eclipse by the faster mechanism \( B_{AC}^2 \) in basic hydrolysis, has been established by Bunnell and co-workers. They examined the reaction of sodium methoxide with methyl benzoate in solvent methyl alcohol. In this system reaction \( B_{AC}^2 \) is a trans-esterification which replaces each original molecule with an identical one and however rapidly this occurs it cannot mask reaction \( B_{AL}^2 \) which was shown to occur by the isolation of diethyl ether:

\[
\text{Me}-\text{O} + \text{Me}-\text{O}-\text{CO}-\text{C}_6\text{H}_5 \rightarrow \text{Me}-\text{O}-\text{Me} + \text{C}-\text{O}-\text{C}_6\text{H}_5
\]

Reaction \( B_{AC}^2 \) involves the attack of a hydroxyl ion on a carbon atom attached directly to the ring system in the case where \( R' \) is aromatic, while reaction \( B_{AL}^2 \) involves attack on a carbon atom further removed from the ring system. It is conceivable that the presence of ortho substituents in the aromatic ring could retard the reaction \( B_{AC}^2 \) to such an extent that reaction \( B_{AL}^2 \) becomes predominant. In 1954, Goering, Rubin and Newman studied the rate of alkaline hydrolysis of several \( \alpha \)-substituted methyl 2,6-dimethylbenzoates and concluded that the hydrolysis was indeed proceeding, at least to a large extent, by mechanism \( B_{AL}^2 \). It has been established that the mechanism of the alkaline hydrolysis of nitro substituted benzoic esters is \( B_{AC}^2 \), but, from the work of Goering, it might be expected that ethyl 2-nitro-1-naphthoate would undergo hydrolysis by mechanism \( B_{AL}^2 \). This ester would provide an even larger steric retardation to the attack of hydroxide ions on the carbon atom closest to the ring than in the case of 2,6-dimethylbenzoates.

It is not easy to show experimentally that the observed rates in this work were indeed second order as has been done for nitro substituted ethyl benzoates, \( B_\text{naphthoate} \) and ethyl 3- and ethyl \( \alpha \)-nitro-1-naphthoates, \( B_{AC}^2 \) by titration procedures. If the reaction is indeed second order it would be expected that the equation used to calculate rate constants would be independent of the
<table>
<thead>
<tr>
<th>Compound</th>
<th>Ref.</th>
<th>$10^3 \kappa (25^\circ \text{C})$</th>
<th>$E$</th>
<th>$\log_{10} \Delta A$</th>
<th>$\Delta \Delta G^\ddagger_{25^\circ \text{C}}$</th>
<th>$\Delta \Delta H^\ddagger$</th>
<th>$(T\Delta A)^\ddagger_{25^\circ \text{C}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethyl benzoate</td>
<td>6</td>
<td>0.628</td>
<td>17.7</td>
<td>9.79</td>
<td>$-$</td>
<td>$-$</td>
<td>$-$</td>
</tr>
<tr>
<td>Ethyl 2-nitrobenzoate</td>
<td>6</td>
<td>5.41</td>
<td>14.5</td>
<td>$8.35 \pm 0.5$</td>
<td>$-1.25$</td>
<td>$-3.2 \pm 0.3$</td>
<td>$-1.97 \pm 0.3$</td>
</tr>
<tr>
<td>Ethyl 3-nitrobenzoate</td>
<td>6</td>
<td>42.9</td>
<td>15.4</td>
<td>9.94</td>
<td>$-2.59$</td>
<td>$-2.1$</td>
<td>$+0.20$</td>
</tr>
<tr>
<td>Ethyl 4-nitrobenzoate</td>
<td>6</td>
<td>72.0</td>
<td>15.0</td>
<td>9.72</td>
<td>$-2.81$</td>
<td>$-2.9$</td>
<td>$-0.10$</td>
</tr>
<tr>
<td>Ethyl 1-naphthoate</td>
<td>13</td>
<td>0.444</td>
<td>11.70</td>
<td>7.41</td>
<td>$-$</td>
<td>$-$</td>
<td>$-$</td>
</tr>
<tr>
<td>Ethyl 2-nitro-1-naphthoate</td>
<td>$-$</td>
<td>0.036</td>
<td>16.62</td>
<td>7.67</td>
<td>$+1.43 \pm 0.3$</td>
<td>$+1.92$</td>
<td>$+0.036$</td>
</tr>
<tr>
<td>Ethyl 3-nitro-1-naphthoate</td>
<td>4</td>
<td>11.0</td>
<td>16.39</td>
<td>10.05</td>
<td>$-1.90$</td>
<td>$+1.69$</td>
<td>$+3.60$</td>
</tr>
<tr>
<td>Ethyl 4-nitro-1-naphthoate</td>
<td>4</td>
<td>12.0</td>
<td>16.20</td>
<td>10.02</td>
<td>$-1.95$</td>
<td>$+1.59$</td>
<td>$+3.56$</td>
</tr>
<tr>
<td>Ethyl 2-nitro-1-naphthoate</td>
<td>$-$</td>
<td>0.0020</td>
<td>19.71</td>
<td>8.66</td>
<td>$+3.23 \pm 0.3$</td>
<td>$+5.04 \pm 0.3$</td>
<td>$+1.72$</td>
</tr>
</tbody>
</table>

**Units**: $\kappa$ is in litre mole$^{-1}$ sec$^{-1}$ and $\Delta \Delta G^\ddagger$, $\Delta \Delta H^\ddagger$ and $T\Delta A$ in kcal mole$^{-1}$.

The rate constants for these esters at $25^\circ \text{C}$ were obtained by substituting $T=298$ in the equation $\log \kappa = \log \kappa^0 - \frac{E}{2.303RT}$.
percentage hydrolysis undergone. Unfortunately it is not possible to continue runs over the long periods of time required, (50% hydrolysis of ethyl 8-nitro-1-naphthoate at 50°C. would occupy over four days), on account of the uncertainty of changes in resistance caused by reasons other than ester hydrolysis. On the other hand it would be unlikely that significant figures would have been derived for Arrhenius activation energies and frequency factors by the application of the equation used to a unimolecular reaction. On theoretical grounds it can, however, be shown that the chance of the reaction being unimolecular is extremely remote. Mechanism BAIL has not yet been reported and is hardly likely to be observed here. This mechanism would involve the ionisation of the ester to form an acylium ion. This process is highly improbable in alkaline solution and especially so in this case as the medium has a fairly low dielectric constant and hence ionising power. Moreover, the nitro substituent in the ring would act against the formation of a positively charged ion. The mechanism BAII is only expected and observed in cases where the structure of R (in a-0-CO-0-R') is such that R² would be comparatively very stable and a solvent of high ionising power would be required. Where R is an ethyl group, as in this case, there is little likelihood of this mechanism occurring.

Rate constants at 35°C., Arrhenius activation energies and frequency factors, relative free energies, heats and temperature - entropy values of activation for nitro substituted ethyl benzoates and ethyl 1-naphthoates are listed in Table I opposite.

An examination of the figures shown in this table reveals several anomalous features in the figures obtained for nitro substituted ethyl 1-naphthoates compared with those obtained for nitro substituted ethyl benzoates. The significant figures are the relative free energies, heats and entropies of activation and these will be discussed in turn.
As the nitro substituent exerts \(-I, -M\) effects, it would be expected to accelerate the reaction and thus negative values of the relative free energy of activation are expected for nitro substituted ethyl 1-naphthoates. This acceleration would be expected to be greatest for derivatives where the nitro group can exert its full \(-M\) effect, except that ortho substituents are expected to accelerate less than would otherwise be expected on account of the steric retardation to the reaction caused by the substituent.

The figures obtained for nitro substituted ethyl benzoates illustrate this expectation. In the case of the nitro substituted naphthoates, two differences must be explained. Firstly, the negative values of the relative free energy of activation for ethyl 2- and ethyl 4-nitro-1-naphthoates are not as large as those for the corresponding benzoic derivatives and furthermore they are nearly equal. This last fact has been explained by Fischer who pointed out that the peri position in the naphthalene ring adjacent to the \(\text{h}\)-substituted nitro group would prevent the latter becoming planar with the naphthalene ring and thus prevent it from exerting its full \(-M\) effect. Secondly, the positive values of the relative free energies of activation obtained for ethyl 2- and ethyl 8-nitro-1-naphthoate are an indication of the considerable amount of steric retardation to the reaction caused by the nitro substituent in each case.

When the relative free energies of activation are resolved into heat and entropy term contributions further anomalies become apparent. Relative heats of activation for the hydrolysis of substituted benzoates appear to be dependent only on polar effects and are negative in cases where the substituents exert \(-I, -M\) effects. Thus ethyl 2- and ethyl 4-nitrobenzoates have approximately equal and negative values of this quantity. In the nitro substituted 1-naphthoates so far studied, however, the values of the relative heat of activation are all positive. On the
other hand, the changes between relative heats of activation as the position of the nitro substituent changes are approximately those expected. That the values are approximately the same for ethyl 2-, ethyl 3- and ethyl 4-nitro-1-naphthoates is explicable if it is considered that the nitro group is prevented from attaining planarity with the naphthalene ring in the 2- and 4- positions. The higher value of the relative heat of activation obtained in the case of ethyl 6-nitro-1-naphthoate is explicable in terms of the smaller polar effect exerted by the 6-nitro substituent compared to that exerted by substituents in the 2-, 3- and 4- positions. In the alkaline hydrolysis of substituted ethyl benzoates studied by Ingold and Nathan and by Watson and co-workers, no significantly positive values of the relative entropy of activation were obtained, and negative values were typical of ortho substituted benzoates. The relative entropies of activation obtained for the nitro substituted ethyl 1-naphthoates, so far studied, are all positive but the changes in this quantity as the position of the nitro substituent alters are those expected. Thus the values of the relative entropy of activation for the 3- and 4- nitro substituted 1-naphthoates are of the same order and greater than those for the 2- and 6- nitro substituted esters, where the nitro group causes steric retardation of the reaction.

The problem presented by the anomalies described above is twofold. Firstly, are the results obtained real and secondly, if they are, what is their theoretical explanation? It has been shown above that the results obtained for the four nitro substituted ethyl 1-naphthoates are consistent with each other but not with the results for ethyl 1-naphthoate itself. The values of the Arrhenius activation energy and frequency factor for each of these five compounds are listed in Table 2. These values were obtained by application of the least squares method to the results from individual runs and the errors shown represent their standard deviations as calculated by standard
The possible errors in the values of the relative heats and entropy-temperature factors have been calculated from the figures above and are listed in Table 2.

### Table 2

<table>
<thead>
<tr>
<th>Compound</th>
<th>$S$ (k. cal. mole$^{-1}$)</th>
<th>log $A$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethyl 1-naphthoate</td>
<td>16.69 ± 0.6</td>
<td>7.41 ± 0.4</td>
</tr>
<tr>
<td>Ethyl 2-nitro-1-naphthoate</td>
<td>16.62 ± 0.75</td>
<td>7.67 ± 0.49</td>
</tr>
<tr>
<td>Ethyl 3-nitro-1-naphthoate</td>
<td>16.39 ± 0.3</td>
<td>10.05 ± 0.2</td>
</tr>
<tr>
<td>Ethyl 4-nitro-1-naphthoate</td>
<td>16.29 ± 0.1</td>
<td>10.02 ± 0.07</td>
</tr>
<tr>
<td>Ethyl 8-nitro-1-naphthoate</td>
<td>19.71 ± 0.36</td>
<td>8.66 ± 0.27</td>
</tr>
</tbody>
</table>

The errors so calculated are much too small to explain the observed anomalies. For instance, while it was expected that the value of $(T_{25}^\Delta S)^*$ for ethyl 4-nitro-1-naphthoate would be close to zero, even after allowing the maximum error in this direction, a value of $+2.91$ is still obtained. It may be significant that the results for ethyl 1-naphthoate were obtained by a titration method while those for the nitro substituted naphthoates were obtained by a conductivity method. However, the results obtained for ethyl 1-naphthoate in this work by a conductivity method, although limited in accuracy by the experimental difficulties previously described, agree fairly well with those of Wilson obtained by a titration method, as shown in Table 4.

### Table 3

<table>
<thead>
<tr>
<th>Compound</th>
<th>$\Delta H^\dagger$</th>
<th>$(T_{25}^\Delta S)^*$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethyl 2-nitro-1-naphthoate</td>
<td>+1.32 ± 1.35</td>
<td>+0.36 ± 1.21</td>
</tr>
<tr>
<td>Ethyl 3-nitro-1-naphthoate</td>
<td>+1.69 ± 0.90</td>
<td>+3.60 ± 0.82</td>
</tr>
<tr>
<td>Ethyl 4-nitro-1-naphthoate</td>
<td>+1.50 ± 0.70</td>
<td>+3.56 ± 0.65</td>
</tr>
<tr>
<td>Ethyl 8-nitro-1-naphthoate</td>
<td>+1.01 ± 0.96</td>
<td>+1.72 ± 0.92</td>
</tr>
</tbody>
</table>

### Table 4

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Titration Method</th>
<th>Conductivity Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>30°C</td>
<td>0.63</td>
<td>0.63</td>
</tr>
<tr>
<td>40°C</td>
<td>1.61</td>
<td>1.61 - 1.35</td>
</tr>
<tr>
<td>50°C</td>
<td>2.9</td>
<td>3.46</td>
</tr>
</tbody>
</table>
Furthermore two titration runs performed by Fischer, one each for ethyl 3- and ethyl 4-nitro-1-naphthoates, give results within 8% of the appropriate conductivity results. As it is difficult to measure the rate of alkaline hydrolysis of ethyl 1-naphthoate by a conductivity method, a conclusive experiment would be the calculation of the Arrhenius activation energy and frequency factor for either ethyl 3- or ethyl 4-nitro-1-naphthoate from rate constants obtained by a titration method. However, it has not been possible to do this in the time available.

The most obvious theoretical explanation of the results would be that the mechanism of the hydrolysis of nitro substituted ethyl 1-naphthoates is different from that of ethyl 1-naphthoate itself. From the discussion of mechanisms given earlier in this work, it is apparent that the mechanisms $B_{AC}^2$ and $B_{AL}^2$ are the only two possibilities. As mechanism $B_{AL}^2$ involves reaction at a site more isolated from the aromatic nucleus than mechanism $B_{AC}^2$, higher values of Arrhenius frequency factors could reasonably be expected.

In the transition state of mechanism $B_{AC}^2$, the naphthalene ring is attached to a carbon atom which has three negatively charged centres attached to it. In mechanism $B_{AL}^2$, the incoming hydroxyl ion attaches itself to the alkyl carbon atom and in the transition state not all the formally negative centres are attached to the carbon atom adjacent to the ring. Hence the electronic energy of activation for the hydrolysis of nitro substituted ethyl 1-naphthoates by mechanism $B_{AL}^2$ would be greater than for the same reaction by mechanism $B_{AC}^2$ and could be greater than the electronic energy of activation of the hydrolysis of ethyl 1-naphthoate by mechanism $B_{AC}^2$. Thus a possible explanation of the results obtained is that nitro substituted ethyl 1-naphthoates undergo alkaline hydrolysis by mechanism $B_{AL}^2$ while ethyl 1-naphthoate itself undergoes hydrolysis by mechanism $B_{AC}^2$. However, while it is reasonable to suppose that 2- and 6-nitro substituents could lead to such
a change in mechanism, there is no acceptable theoretical reason why ethyl 3- and ethyl 4-nitro-1-naphthoates should undergo hydrolysis by any mechanism other than that by which ethyl 1-naphthoate is hydrolysed. Furthermore, as Fischer has pointed out, in the case of ethyl 2- and ethyl 2-nitro-1-naphthoates if the nitro substituted ethyl 1-naphthoate reacts by mechanism \( B_{AL}^2 \) then

\[
\frac{k(B_{AC2})}{k(B_{AL2})} < 1
\]

and if the unsubstituted ethyl 1-naphthoate reacts by mechanism \( B_{AC2} \)

\[
\frac{k_0(B_{AC2})}{k_0(B_{AL2})} > 1
\]

Hence

\[
\frac{k_{EC}(B_{AC2})}{k_{EC}(B_{AL2})} < \frac{k_0(B_{AC2})}{k_0(B_{AL2})}
\]

\[
\sigma_{NO2}^0(B_{AC2}) < \sigma_{NO2}^0(B_{AL2})
\]

and since \( \sigma \) is independent of mechanism

\[
\sigma(B_{AC2}) < \sigma(B_{AL2})
\]

This conclusion is contrary to theoretical expectations and to the work of Goering, Rubin and Newman. These workers studied the rates of alkaline hydrolysis of \( 4 \)-substituted methyl 2:6-dimethylbenzoates in dioxan-water (60:40 by volume) at temperatures from 82 to 171°C. The Arrhenius frequency factors obtained were larger than they expected by comparison with those for mon-ortho substituted benzoates and they therefore postulated that methyl 2:6-dimethylbenzoates underwent alkaline hydrolysis by mechanism \( B_{AL}^2 \). In support of this, they calculated the Hammett rho constant for the reaction by plotting \( \log k_{125°C} \) against Hammett's sigma constants for the \( 4 \)-substituted derivatives. The sigma values were used as though the 2- and 6-methyl groups were absent, and methyl 2:6-dimethylbenzoate was given the sigma value of 0.00. In this manner they obtained a rho value of +1.26 for the reaction and compared this with the values +2.50, found in case of the basic hydrolysis of unhindered ethyl benzoates in 87.53% ethanolic at 30°C, and +2.37, for the same reaction in 56% acetone at 25°C. The rho value for the hydrolysis of ethyl benzenesulphonic esters, known to
proceed by alkyl-oxygen fission, is + 1.19 and they assumed that the agreement of their value, + 1.26, with this figure supported the assumption that alkyl-oxygen fission took place in the hydrolysis of methyl 2:6-dimethylbenzoate. Thus a decrease in the rho value would be expected to result from a change in the mechanism from $B_{A02}$ to $B_{A12}$. Therefore, from the argument above, if ethyl 3- and ethyl 4-nitro-1-naphthoate are hydrolysed by mechanism $B_{A12}$, while ethyl 1-naphthoate is hydrolysed by mechanism $B_{A02}$, the Hammett equation cannot be applied to these compounds. The only conceivable explanation for this would be that the nitro substituent modifies the configuration of either the naphthalene nucleus or the side chain.

As the four nitro substituted ethyl 1-naphthoates studied appear to be hydrolysed by the same mechanism, it is also necessary to consider the probable mechanism of the hydrolysis of ethyl 2- and ethyl 6-nitro-1-naphthoate. If methyl 2:6-dimethylbenzoates undergo hydrolysis by mechanism $B_{A12}$, it might reasonably be expected that ethyl 2-nitro-1-naphthoate would also be hydrolysed by this mechanism. However, there are certain anomalies in the work of Goeing, Rubin and Newman that are worth considering. Firstly, they compared Arrhenius frequency factors obtained for methyl 2:6-dimethylbenzoates in dioxan-water with figures obtained for ortho substituted benzoates in other solvents as evidence for a change in mechanism and the validity of this is somewhat doubtful. Furthermore, values of Hammett rho constants are markedly temperature dependent and theoretically:

$$\rho \propto \frac{1}{T}$$

Rho constants have been calculated from the results of Tomilla for the alkaline hydrolysis of methyl benzoate in 60% acetone in the temperature range 0 - 50°C. If these figures are extrapolated against $T^{-1}$ to $T = 398^\circ$, a value of about 1.5 is obtained for $\rho$ at $25^\circ$. Allowing for errors in extrapolation and for differences in solvents,
this value is not greatly different from that obtained by Goering for methyl 2,6-dimethylbenzoates. As there is no reason to suppose that mechanism $B_{AL}^2$ predominates over mechanism $B_{AO}^2$ in the case of the alkaline hydrolysis of methyl benzoate at 125°C, the comparisons made by Goering between the rho value for methyl dimethylbenzoates at 125°C and rho values for other esters, in different solvents and at different temperatures, is of doubtful validity. Goering and co-workers also investigated the hydrolysis using $c^{18}$ but the results were inconclusive. Thus, until further work is performed, it is difficult to reach definite conclusions in relation to their work.

The Arrhenius plot for ethyl 2-nitro-1-naphthoate (page 59) appears to be non-linear, and this non-linearity is somewhat greater than can be reasonably explained as an experimental discrepancy. It is possible that it represents an increasing amount of hydrolysis occurring by mechanism $B_{AL}^2$ as the temperature rises and the temperature-entropy term in the relative free energy becomes more important. However, if this assumption is correct, ethyl 3- and ethyl 1-nitro-1-naphthoates would be expected to hydrolyse by mechanism $B_{AO}^2$ and the discrepancies already discussed become inexplicable.

No explanation can thus be advanced for the anomalies found in the rates of alkaline hydrolysis of nitro substituted ethyl 1-naphthoates, unless it is assumed that the nitro substituent can modify the configuration of either the naphthalene nucleus or the attached side chain. The study of the alkaline hydrolysis of other substituted ethyl 1-naphthoates would show whether these discrepancies are typical of the nitro substituent or of substituted 1-naphthoates as a whole. Suitable substituents would be the chloro (−I, +M) group and the methyl (+I, +M) group.
MECHANISM OF THE CONDENSATION OF AROMATIC NITRO-METHYL COMPOUNDS WITH DIETHYL OXALATE

In any postulation of the mechanism involved in the condensation of nitrotoluene or nitro-methylnaphthalenes with diethyl oxalate under the influence of ethoxide ions, the following facts must be considered.

(i) Reissert (1897) showed that when either ortho or para nitrotoluene were heated under reflux for short periods of time with diethyl oxalate and sodium ethoxide, followed by addition of the reaction mixture to water, then the corresponding nitrophenylpyruvic acids were obtained. He assumed that the initial product of the reaction was the ethyl nitrophenylpyruvate but that this was spontaneously hydrolysed on its formation to the acid, e.g. in the case of 2-nitrotoluene:

Reissert detected the formation of some 4;4'-dinitro-dibenzyl (IV) as a byproduct in the case of 4-nitrotoluene. He also obtained some 2;2'-dinitro-dibenzyl (V) as a byproduct on decomposing 2-nitrophenylpyruvic acid (III) with aqueous alkali.

(ii) Mayer and Oppenheimer (1916) attempted to prepare analogous derivatives in the naphthalene series using a similar procedure to that above. However, the only product obtained on condensing diethyl oxalate with 4-nitro-1-methylnaphthalene was 4;4'-dinitronaphthyl-1:1'-ethane. In the case of 1-nitro-2-methylnaphthalene the main pro-
duct was 1-nitro-2-naphthylpyruvic acid, but, in the Author's experience, 1:1'-dinitronaphthyl-2:2'-ethane (VI) is also obtained.

(VI)

(iii) Wislicenus, Thoma and Schultz (1924) investigated the condensation of ortho and para nitrotoluenes with diethyl oxalate under the influence of potassium ethoxide in the cold. The primary product obtained in each case was the potassium derivative of the ethyl nitrophenylpyruvate to which they ascribed a quinonoid type structure e.g. (VII)

(VII)

They found that these yielded the corresponding nitrophenylpyruvic acids on treatment with water and the ethyl nitrophenylpyruvate on treatment with dilute acid, thus explaining Reissert's failure to obtain the latter. Furthermore, they noted that no binuclear condensed compounds could be detected in the condensation of 2-nitrotoluene but with 2-nitrotoluene both 4:4'-dinitrodibenzyl (IV) and 4:4'-dinitrostilbene (VIII) were obtained.

(VIII)

They also showed that neither of these condensed derivatives was produced in the absence of diethyl oxalate, nor if dimethyl oxalate was employed.
(iv) Wislicenus and Mundinger (1924) showed that when 1-nitro-2-methylnaphthalene was condensed with the calculated amounts of diethyl oxalate and potassium ethoxide in the cold and the products added to water, then 1-nitro-2-naphthylpyruvic acid was the main product. If twice the calculated amount of potassium ethoxide was employed the dinitronaphthyl-ethane (VI) was the main product, while an excess of diethyl oxalate repressed the formation of this.

(v) The present work showed that if 2-nitro-1-methylnaphthalene (IX) was condensed with diethyl oxalate by Reissert's procedure, then a mixture of 2:2'-dinitronaphthyl-1:1'-ethane (XIII) and 2-nitro-1-naphthylpyruvic acid was obtained. When the procedure of Wislicenus was employed, using the calculated quantities of reagents, then a mixture of the same two compounds was obtained. Using a large excess of diethyl oxalate and then adding the reaction mixture to either water or dilute acid resulted in a yield of ethyl 2-nitro-1-naphthylpyruvate (XI) with only a small amount of the binuclear condensed compound. On hydrolysing the ethyl pyruvate (XI) to 2-nitro-1-naphthylpyruvic acid with either aqueous or alcoholic potassium hydroxide solution, 2-nitro-1-methylnaphthalene and 2:2'-dinitronaphthyl-1:1'-ethane were obtained as byproducts.

The mechanism proposed has, as a first step, the initial formation of a carbamion by the action of ethoxide ions on the aromatic nitro-methyl compound e.g.

The formation of this carbamion would be made possible by the powerful -I, -M, effect of the conjugated nitro group. The next step proposed is the formation of the naphthylpyruvic acid ester, by reaction of this carbamion
with diethyl oxalate, and the subsequent productions of the potassium derivative (XII):

\[
\text{(XII)}
\]

It is suggested that the formation of the ester (XI) is a necessary intermediate step in the formation of a binuclear condensed derivative. The formation of 2:2'‐dinitronaphthyl‐1:1'‐ethane by attack of the carbanion (X) on 2‐nitro‐1‐methylnaphthalene is unlikely as it would result in the liberation of a hydride ion. A more feasible suggestion is that the condensed compound is formed by attack of the carbanion (X) on \( O_1 \) of the ester (XI), with the release of an unstable carbanion that would subsequently decompose. This step, while slow, would be irreversible.
Excess diethyl oxalate would hinder it as it would tend to convert the carbanion (X) to the ester (XI). Alternatively the presence of excess ethoxide ions might be expected to aid the formation of the same carbanion.

The alkaline hydrolysis of the ester (XI) to 2-nitro-1-naphthylpyruvic acid would occur by attack of hydroxyl ions on C\(_3\) with the release of ethoxide ions. When the potassium derivative (XII) is added to water an equimolar amount of hydroxide ions would be produced and hydrolysis of the ester would thus be expected. The failure of this to occur in the case of the 2-nitro-1-naphthyl derivative is probably caused by the presence of the more readily hydrolysed diethyl oxalate as an impurity in the potassium salt.

The products obtained on alkaline hydrolysis of the ester (XI) can be explained on the basis of the mechanism postulated above. Attack by hydroxide ions on C\(_3\) would lead to the pyruvic acid and on C\(_2\) to the production of the carbanion (X).

![Diagram](image)

Once the carbanion is formed the presence of 2-nitro-1-methylnaphthalene and the condensed derivative can be explained.

In support of this mechanism it was found that 2-nitro-1-methylnaphthalene was unchanged even after long exposure to potassium ethoxide. Thus, as postulated by Wislicenus, diethyl oxalate would appear to be essential to the production of a condensed derivative. It was also shown that when ethyl 2-nitro-1-naphthylpyruvate was exposed to excess potassium ethoxide for several days and the solution subsequently acidified then 2-nitro-1-methylnaphthalene and a small amount of 2,2'-dinitro-naphthyl-1:1'-ethane were produced.
The reason for the formation of binuclear condensed derivatives in the case of 2-nitrotoluene but not in the case of 2-nitrotoluene, and for the production of only 4:4'-dinitronaphthyl-1:1'-ethane from 1-nitro-1-methyl- naphthalene under conditions where 1-nitro-2-methylnaphthalene would yield the nitronaphthylpyruvic acid is probably a steric one. The production of a condensed derivative has been postulated to be irreversible but in the case of 2- nitrotoluene, 2-nitro-1-methylnaphthalene and 1-nitro-2- methylnaphthalene it would be expected that there would be considerable steric hindrance to an attack by the corresponding carbonium on the carbon of the pyruvic-acid group closest to the ring.

The postulations above are not conclusive but they do explain the known facts. Further experimental work is necessary to check the mechanism suggested.
THE EVALUATION OF RATE CONSTANTS FROM RESISTANCE DATA

The second order rate equation for equivalent concentrations of the two reactants is

\[ \frac{dX}{dt} = k (A_0 - x)^2 \]  \hspace{1cm} (1)

where \( x \) is the decrease in molar concentration of either of the reactants in time \( t \), \( A_0 \) is the initial concentration of either of the reactants and \( k \) is the rate constant. Integration of this equation and substitution of the condition that \( x = 0 \) at \( t = 0 \) gives

\[ \frac{x}{A_0(A_0 - x)} = kt \]  \hspace{1cm} (2)

Fischer has shown that for the alkaline hydrolysis of carboxylic acid esters in ethanol-water

\[ x = aR^{-1} + b \]  \hspace{1cm} (3)

where \( R \) is the measured resistance and \( a \) and \( b \) are constants.

At \( x = 0 \), define \( R \) as \( R_o \),

\[ : 0 = aR_o^{-1} + b \]  \hspace{1cm} (4)

At \( x = A_0 \), define \( R \) as \( R_\infty \),

\[ \therefore A_0 = aR_\infty^{-1} + b \]  \hspace{1cm} (5)

Eliminating \( a \) and \( b \) from equations (3), (4) and (5)

\[ x = \frac{A_0R_o}{R} x \frac{R - R_o}{R_\infty - R_o} \]  \hspace{1cm} (6)

Eliminating \( x \) between (2) and (6), and rearranging

\[ R = \frac{R_oA_0k}{R_\infty} (R_\infty - R) + R_o \]  \hspace{1cm} (7)

Fischer considered, in detail, the evaluation of rate constants from this equation and its rearranged forms, and derived the equation used for procedures (a) and (b) of this work (See Page 50), and which he considered to be the most useful for the determination of rate constants from resistance data. However an examination of equation (7) shows that a graph of resistance against time for a run would have a slope, \( P \), given at any point \( R_p \) by

\[ P = \left( \frac{R_0A_0k}{R_\infty} \right) (R_\infty - R_p) \]  \hspace{1cm} (8)
and an intercept with the resistance axis given by $R_0$. It is not feasible to measure $R_0$ directly as this would involve simultaneous mixing of the cell contents and a measurement of resistance, while it is preferable to remove the cell from the thermostatted bath during mixing. However, in a case where the rate of hydrolysis is low, the change in resistance with time is small and thus a graph of $R$ against $t$ can be extrapolated to give $R_0$ with some certainty. The error in $k$ is only the percentage error in $R_0$. On rearrangement of equation (7)

$$R = -\frac{R_0}{K_n a c K} \frac{(R - R_0)}{t} + R_0$$

and thus $R_0$ could be calculated from the gradient of a graph of $R$ against $(R - R_0)/t$. However the term $(R - R_0)$ would be inaccurate due to the necessity for the extrapolation above to obtain $R_0$. It is therefore preferable to measure the resistance of a cell containing a solution which is equivalent to that expected after total hydrolysis.

The largest error involved in this method is the calculation of the gradient $\frac{\partial}{\partial t}$ from a graph of $R$ against $t$. If the rate of hydrolysis is small, and therefore the graph nearly linear, this is best done by fitting the best straight line to a graph taken over a relatively short period of time, and taking $R_P$ from the mid-point of this graph. The method could also be applied to compounds with higher rate constants than met in this work by using a lower temperature and a lower value of $A_0$ to reduce the rate of hydrolysis. The limiting factor here would be when the quantity of ester to be weighed out became so small as to introduce significant error in its measurement.
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