THE OPTICAL ACTIVITY OF CARBON AND SULPHUR COMPOUNDS

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This thesis is an account of an experimental study of the optical activity of organic compounds which had two main objectives:

(a) the collection of evidence as to the causes underlying the phenomenon of complex rotatory dispersion,

(b) the study and detection of new types of asymmetry.

These main objectives are not necessarily disconnected since Arndtsen, Armstrong and Walker, Lowry and others have suggested that substances exhibiting complex rotatory dispersion may contain two components with different rotatory and rotatory dispersive powers. Further, a suggestion advanced more recently by Lowry includes the possibility that such labile components or isodynamic forms of an optically active compound may contain an additional optically active centre, arising from labile intra-molecular valency changes. Such labile valency changes have long been postulated as the underlying causes of the complex rotatory dispersion of the esters derived from the optically active secondary alcohols and the n-aliphatic carboxylic acids. That a carboalkyloxy group or other
oxygen containing group is not in itself essential for the production of complex rotatory dispersion is shown in Part I of this thesis in which an optically active aromatic hydrocarbon is described, the rotatory dispersion of which is complex.

In Part II the resolution of two 'mixed' sulfoxides is described. They are the first two compounds of this type to be resolved and their resolution substantiates the recent work of Phillips and at the same time confirms the existence of a new type of asymmetry and the existence of the semi-polar double bond.

Throughout these investigations full use has been made of the fresh outlook supplied to the problems under review by the newer electronic theories of valency. In Part III possible variations of the accepted formula for urethanes are discussed from this standpoint and an account is given of an attempt to effect the resolution of ethylphenylcarbamate into its possible optically active or optically inactive dynamic isomerides, using the experimental methods developed by Phillips not hitherto employed in the investigation of nitrogen compounds. The results obtained indicate that if urethanes exist as a mixture of enantiomorphous or labile isomeric forms these are incapable of resolution by the methods employed, but nevertheless new and interesting data have been obtained concerning the optical dispersive powers of this class of compounds.
PART I

THE PREPARATION AND OPTICAL PROPERTIES OF d-sec.-BUTYLBENZENE.

Simple and Complex Dispersion.

Optical Rotatory Dispersion is one of the most interesting of the phenomena encountered in the study of the optical activity of organic compounds and optically active compounds can be classified according as their optical rotatory dispersive powers are simple or complex.

Shortly after 1815 when he discovered the rotatory power of organic compounds Biot published a dispersion equation according to which "the rotation of the different simple rays is reciprocal to the square of their wave lengths". Within a few years of its announcement Biot suspected that this law was not rigidly obeyed by all optically active compounds, a suspicion which he confirmed experimentally in 1836 by showing that it was impossible to compensate a laevorotatory column of turpentine by means of a dextrorotatory column of oil of lemon for light of more than one wave length. (Compt.rend. 2, 543.).

After the discovery of the anomalous rotatory dispersion of tartaric acid Biot divided optically active substances into two classes:-

(a) those which obeyed the inverse square law fairly accurately, the rotatory power increasing with decreasing wave length, and
(b) those which did not obey the inverse square law, some (tartaric acid, for example) increasing in rotatory power in certain parts of the spectrum with increasing wave length.

Many attempts were made to obtain a dispersion equation which would accurately represent the behaviour of as many substances as possible over as wide a range of the spectrum as could be observed. Very little success was achieved with the numerous empirical equations which were suggested until Drude in 1898 deduced mathematically the equation which bears his name:

$$\alpha = \sum \frac{k^2}{(\lambda^2 - \lambda_0^2)}$$

In this equation $k_0$ is a constant which depends upon the substance under investigation; $\lambda$ is the wave length of the light employed whilst $\lambda_0^2$ may be regarded as the dispersion parameter whilst $\lambda_0$ is the wave length of the disturbance corresponding to the frequency at which the substance is capable of absorbing energy. There is one term in this equation corresponding to every "rotatory electron" which is contributing rotatory dispersion. If the optical rotatory power of a substance for light of any wave length can be expressed by a Drude equation of one term, the substance is said to show simple rotatory dispersive power; on the other hand, should two or more terms be required to predict accurately the rotatory power of a substance for light of any desired wave length, the substance is classified as exhibiting complex rotatory dispersion.
The Drude equation, however, was not brought into general use until 1912.

The motatory dispersion of the majority of optically active organic compounds can be represented by a Drude equation of one term, and that of almost the whole of the remainder can be satisfied by an equation of two terms. This is probably because it is very difficult, with the polarimetric apparatus at present available, to detect such small differences as would be involved by the use of a third term in the Drude equation.

A rough practical method of deciding whether the dispersion of a substance is simple or complex consists in determining the rotatory power for light of several different wave lengths and plotting a graph showing the relationship between $\frac{1}{A}$ and $\lambda^2$. If a straight line can be drawn through the points obtained the dispersive power of the substance is probably simple. This method, however, is not sufficiently accurate to detect the small deviations which often occur; if a straight line is indicated the conclusion should always be confirmed by determining the values of $k_0$ and $\lambda_0$ from any two of the rotatory powers observed: the values of the constants may then be substituted in the Drude equation from which the rotatory power for all the other wave lengths can be calculated. If these agree closely with the observed values it may be concluded that the substance exhibits simple rotatory dispersion.
Investigations on the Origin of Complex Rotatory Dispersion.

It has been known ever since the experiments of Biot, that complex rotatory dispersion can be produced by the superposition in a transparent medium of two simple partial rotations with unequal dispersion ratios.

The difficulty of the problem lies in the attempt to discover the origin of the second partial rotation in an apparently homogeneous medium which is exhibiting complex rotatory dispersion. In this connection Lowry and Cottrell (J., 1925, 127, 604) have made a classification of the various sources from which the second partial rotation may arise.

A large class of compounds which exhibit complex rotatory dispersion are the esters derived from carboxylic acids and optically active aliphatic secondary alcohols.

These esters and the alcohols from which they are derived have been the subject of an extensive study from the standpoint of optical rotatory dispersive power (Pickard and Kenyon, J., 1911, 99, 45 et seq.), since, although the alcohols show simple dispersive power the esters are almost invariably complex. An alternative form of the carboxyl group was suggested by Smedley (J., 1909, 95, 931) and the suggestion was adopted by Pickard and Kenyon (J., 1914, 105, 830) to explain the complex rotatory dispersion of these esters, which they considered might exist in two isodynamic forms.
This explanation was quite empirical and the second, hypothetical form of the ester has not yet been shown definitely to exist.

Since this suggestion was made the investigations have been extended to other classes of compounds with the object of determining the causes underlying the phenomenon of complex rotatory dispersion. It has been found that secondary alcohols of similar constitution which contain a phenyl group are complex (Kenyon and Hewitt, J., 1925, 127, 1094) and the complexity is ascribed in this case to the tautomerism of the benzene ring suggested by Ingold.

Kenyon and Snellgrove (J.,) 1925, 127, 1169) have shown that the presence of an ethylenic linking in secondary alcohols which contain the vinyl group does not cause complex dispersion, although here again the esters derived from these alcohols are complex.

The n-aliphatic ethers derived from one of the aliphatic secondary alcohols (d-γ-nonanol) have been examined and cases of complex dispersion have been found in which it has not been possible to suggest isodynamic forms, (Kenyon and Barnes, J., 1924, 125, 1395).

The subject presents many difficulties and it seems that the only method of determining with certainty the causes of complex rotatory dispersion is to examine as many different classes of optically active compounds as it is possible to prepare. With this object in view it was decided to prepare and examine an
optically active hydrocarbon, a compound from which the
carboalkyloxy1 and other oxygenated groups are absent.
Very few optically active hydrocarbons have so far been described
and no information concerning their dispersive powers is
available. The majority of those which are known are of
complex structure, containing more than one asymmetric centre.
Among the optically active hydrocarbons which have been described
are:

\[ \text{d-methylethyl-}n\text{-propylmethane, } [\alpha]_D^{20} +9.5^\circ \text{ which was prepared by Marckwald (Ber., 1904, 37, 1048) by the action of}
\]
sodium on a mixture of ethyl iodide and d-amyl iodide.

\[ \text{d-}\alpha \text{-phenyl-}\gamma\text{-methylpentane ( } [\alpha]_D^{14.5} +17.2^\circ \) prepared by Klages and Sautter (Ber., 1904, 37, 649) by the}
\]
reduction of d-\(\alpha\)-phenyl-\(\gamma\)-methyl-\(\Delta^2\)-pentene ( \( [\alpha]_D^{12} +43^\circ \),
\]
which was prepared by the interaction of amyl iodide ( \( [\alpha]_D^{15} +5.78^\circ \) and benzaldehyde in the presence of magnesium. In a
similar way these authors (Ber., 1905, 38, 2312) prepared
\[ \text{d-}\gamma\text{-m-iso} \text{propylphenyl-}\gamma\text{-methylpentane ( } [\alpha]_D^{15.5} +15.91^\circ \) and d-\(\gamma\)-m-iso}
\]
propylphenyl-\(\gamma\)-methyl-\(\Delta^2\)-pentene ( \( [\alpha]_D^{16} +41.89^\circ \))

A number of optically active hydrocarbons of
complex constitution were prepared by Rupe and his collaborators
(Ber., 1906, 39, 1119), by the action of alkylmagnesium
halides on optically active aldehydes and ketones such as
citronellal, carvone and isopulegone.
None of the optically active hydrocarbons previously prepared appeared to be suitable for the present investigation; it was therefore decided to prepare and resolve a hydrocarbon which was likely to be the most suitable, having regard to the following considerations:

(1). The substance should be of simple constitution and contain only one asymmetric centre.

(2). The substance should, if possible, be a member of a homologous series so that its optical properties could be compared with those of the other members of the series.

A member of the series of simple hydrocarbons which have the general formula \( C_6H_5(CH_3)CH.R \), was chosen — namely dl-sec.-Butylbenzene — since it fulfils both these requirements and is readily accessible in large quantities.
The Resolution of dl-sec.-Butylbenzene.

Since dl-sec.-Butylbenzene could not be resolved by direct combination with an optically active substance, a method was sought which would depend upon the introduction and subsequent removal of a group which would enable it to combine with an optically active acid or base.

A previous unsuccessful attempt was made on these lines by Klages (Ber., 1906, 39, 2131) who prepared dl-sec.-Butylbenzene-sulphonic acid and recrystallised the salts which it forms with quinine, cinchonidine and strychnine, but without effecting a separation into the two optically active forms. It was therefore decided to attempt the resolution by the introduction of an amino group, which can easily be removed from the benzene ring by the process of diazotisation. This method of attack proved successful, so that after preliminary investigations in the preparation of dl-p-amino-sec.-Butylbenzene, Mr Shepherd (Thesis to the University of London, 1924) was able to show that the recrystallisation of the salt formed with d-tartaric acid caused a separation of the optically active forms.

Shortly before this a paper had appeared by two American authors, Glattfeld and Wertheim (J. Amer. Chem. Soc., 1921, 43, 2682) in which they described the preparation and resolution of this substance by recrystallisation of the salt which it forms with d-camphorsulphonic acid. The rotatory power of the amine which is described by these authors as optically pure
is, however, almost negligible ($\delta_D = 0.26^\circ$, $l = 0.5$).

d-$p$-Amino-sec.-Butylbenzene prepared in the course of the present work has a rotatory power some sixty times as great as this value.

The method used consisted in nitrating dl-sec.-butylbenzene and, after reduction of the nitro compound to the amine, the removal of the ortho and meta isomerides which the product contained by recrystallisation of the neutral salts formed with oxalic acid.

The most satisfactory method of resolution was the recrystallisation of the $d$-hydrogen tartrate of the amine from aqueous solution: other optically active acids and other solvents were tried, but with little success. dl-$p$-Amino-sec.-butylbenzene $d$-hydrogen tartrate was systematically recrystallised and after twenty-seven recrystallisations of the main crop the amine recovered from a small portion was considered to be optically pure since its rotatory power was not increased by three further recrystallisations of the main crop. $d$-$p$-Amino-sec.-butylbenzene had $[\alpha]_D^{20^\circ} = 40.98^\circ$ and $[\alpha]_D^{5893} = 33.86^\circ$.

A great difficulty encountered was the relatively slow rate of separation of the enantiomorphous forms, which entailed considerable wastage of material. The use of water was also inconvenient since, in order to minimise the hydrolysis of the salt it was necessary to add additional tartraric acid at each recrystallisation.
1-† dl-p-Amino-sec.-Butylbenzene.

In spite of many attempts the laevorotatory isomeride could not be obtained in an optically pure condition. The amine recovered with $[\alpha]_D^{20°} = -20°$ from the more soluble fractions of the recrystallisation of the dl-p-amino-sec.-butylbenzene d-hydrogen tartrate was combined with several optically active and inactive acids, but, on decomposition of the salts thus obtained after many recrystallisations from various solvents, the amine was recovered unchanged in rotatory power.
d-sec.-Butylbenzene.

_d-p_-Amino-sec.-butylbenzene was diazotised and the corresponding diazonium chloride obtained reduced in aqueous solution by the method of Friedländer (Ber., 1889, 22, 587) to the required d-sec.-butylbenzene. It was necessary, of course, to demonstrate at this stage that the d-sec.-butylbenzene thus prepared was equal in optical purity to the d-p-amino-sec.-butylbenzene from which it was obtained, for it is conceivable that during the removal of the amino group the valencies of the benzene ring might be disturbed as to cause a corresponding disturbance of the valencies of the corresponding asymmetric carbon atom to which it is united. The annexed scheme indicates a possible course for the reaction.

\[ \text{CH}_3 - \text{C} - \text{H} \quad \text{C}_2\text{H}_5 \]

That no such disturbance of the valencies of the asymmetric carbon atom occurs, and hence that the hydrocarbon is obtained from the amine without loss of optical purity was proved by repetition of the reaction under various experimental conditions, when it was found that the rotatory power of the hydrocarbon and of the amine used bore a constant ratio to each other.

It is interesting to note in this connection that Klages
and Sautter (Ber., 1905, 38, 2312) converted d-2-ethoxy-1-\(\gamma\)-methyl-
amylobenzene into a sulphonic acid derivative and by heating the
latter with hydrochloric acid at 150° for five hours were able
to recover the original compound unchanged in rotatory power.

d-sec.-Butylbenzene which was obtained by\(\theta\) the method
outlined had b.p. 172° and \([\alpha]_5461^{20°} = +33.15°\), whilst an examination
of the rotatory powers for light of other wave lengths showed that
the hydrocarbon exhibits complex rotatory dispersion.

It is obvious from this result that the benzene nucleus,
which may be considered to exist in isodynamic forms may, alone,
be responsible for complex rotatory dispersion in the absence of
the carboalkylcycloxy and other oxygen containing groups. Attempts
were accordingly made to reduce sec.-butylbenzene to sec-butyl-
cyclchexane, in which such dynamic isomerism cannot occur, in order
to ascertain what effect the loss of aromatic character would
have on the rotatory dispersive power. The method employed
consisted in agitating the substance in acetic acid solution with
varying amounts of colloidal platinum and palladium in an
atmosphere of hydrogen, but, under the conditions of the
experiments very little, if any, reduction was effected.
Determinations of Density and Refractive Index.

Density.

$d_{sec}$-Butylbenzene.  $d_{15}^{15}$ 0.8681,  $d_{20}^{20}$ 0.8639,  $d_{25}^{25}$ 0.8590.

$d_{p}$-Amino-$sec$-butylbenzene.  0.9475,  0.9449,  0.9411.

$dl$-$p$-Nitro-$sec$-butylbenzene.  1.063.

Refractive Index.  \(\lambda = 6708, 5893, 5790, 5461, 4359\).

$\lambda_{25}^{25}$.

$d_{sec}$-Butylbenzene.  1.4838 1.4883 1.4900 1.4915 1.5061.

$d_{p}$-Amino-$sec$-butylbenzene.  1.5284 1.5346 1.5356 1.5391 1.5589.

$dl$-$p$-Nitro-$sec$-butylbenzene.  -- -- 1.5322 1.5363 1.5622.
### TABLE II.

**Determinations of Rotatory Power**

*d*-p-Amino-sec.-butyl benzene. \(d_{20}^0 = 0.9449\)

<table>
<thead>
<tr>
<th>Solvent</th>
<th>G. of solute in 100 c.c.,</th>
<th>l in 1 mm.</th>
<th>6708</th>
<th>5896</th>
<th>5790</th>
<th>5461</th>
<th>4359</th>
<th>6708</th>
<th>5896</th>
<th>5790</th>
<th>5461</th>
<th>4359</th>
</tr>
</thead>
<tbody>
<tr>
<td>Homogeneous</td>
<td>-</td>
<td>25</td>
<td>+5.85</td>
<td>+8.00</td>
<td>+8.37</td>
<td>+9.68</td>
<td>+18.10</td>
<td>+24.75</td>
<td>+33.86</td>
<td>+35.42</td>
<td>+40.98</td>
<td>+76.6</td>
</tr>
<tr>
<td>Ethyl alcohol</td>
<td>4.94</td>
<td>100</td>
<td>1.31</td>
<td>1.76</td>
<td>-</td>
<td>2.05</td>
<td>3.75</td>
<td>26.5</td>
<td>35.6</td>
<td>-</td>
<td>41.5</td>
<td>75.8</td>
</tr>
<tr>
<td>Carbon disulphide</td>
<td>5.01</td>
<td>100</td>
<td>1.45</td>
<td>2.00</td>
<td>-</td>
<td>2.44</td>
<td>4.96</td>
<td>28.9</td>
<td>39.9</td>
<td>-</td>
<td>48.7</td>
<td>99.0</td>
</tr>
<tr>
<td>Chloroform</td>
<td>5.02</td>
<td>100</td>
<td>1.15</td>
<td>1.63</td>
<td>1.72</td>
<td>2.00</td>
<td>3.72</td>
<td>22.9</td>
<td>32.5</td>
<td>34.3</td>
<td>39.8</td>
<td>74.1</td>
</tr>
</tbody>
</table>

**d*-p-sec.-Butyl acetanilide. M. p. 124°**

| Chloroform    | 4.99                     | 100        | 0.97  | 1.34  | 1.40  | 1.58  | 2.00   | 19.4   | 26.8   | 28.0  | 31.6  | 58.1 |

**d*-sec.-Butyl benzene. \(d_{20}^0 = 0.8639\).**

| Homogeneous   | -                        | 25         | 4.41  | 5.90  | 6.19  | 7.14  | 12.96  | 20.42  | 27.31  | 28.66 | 33.15 | 60.0 |
THE RESOLUTION OF SULPHOXIDES INTO THEIR OPTICALLY ACTIVE FORMS.

The resolution of sulphoxides into their optically active forms, the subject of this section, amplifies the distinct advance in our knowledge of the stereochemistry and constitution of organic compounds of sulphur which was made by Phillips (J., 1925, 127, 2552).

A brief historical and critical survey of the optically active compounds of sulphur hitherto prepared will indicate clearly the important nature of the results to be described. The subject will be reviewed from two distinct standpoints, namely:

(a) the classical theories of valency,
(b) the newer electronic theories of valency.

(a)

The Optically Active Sulphur Compounds of Pope and Peachey.

Pope and Peachey (J., 1900, 77, 1072) described the first optically active organic compound, the activity of which could be attributed to the sulphur atom which it contained. These workers obtained methylethylthetine d-camphorsulphonate by the interaction of methylethylthetine bromide and silver d-camphorsulphonate, and on recrystallisation this salt was
separated into two forms which differed considerably in their rotatory power. On replacement of the $d$-camphorsulphonate radicle by an optically inactive group, such as the platinichloride radicle, two optically active salts of the thetine were obtained with rotatory powers of opposite signs. The optical activity was therefore due to the sulphur atom of the thetine and was not dependent on the presence of the optically active $d$-camphorsulphonic grouping.

The work was shortly afterwards extended by these authors to compounds of selenium and by Smiles (J., 1900, 77, 1174) to sulphines of the type:

$$\text{CH}_3 \text{S-SCH}_2 \text{CO-CO}_2 \text{H}_5$$

(methylethylsulphine compound of $\omega$-bromacetophenone).

Pope and Peachey concluded that the asymmetry of their compounds was strictly similar to the asymmetry of a compound of quadrivalent carbon in which the central atom is attached to four different elements or groups by four valency bonds of equal value.

$$R' - S - R''$$

The same view was adopted later on by Smiles concerning the optical activity of the sulphines. On the other hand, however, Werner (Lehrbuch der Stereochemie, 1904, p.317) as a result of his investigations on co-ordination compounds concluded that there was more than one type of valency bond.
and he suggested that the explanation offered by Pope and Peachey was incorrect and that the fourth valency of the quadrivalent sulphur atom was different from the other three.

\[ \begin{align*}
A & \quad S \\
B & \quad C
\end{align*} \]

Werner maintained that in the compounds of Pope and Peachey and Smiles the systems

\[ \begin{align*}
A & \quad S \\
B & \quad C \\
\text{and} & \quad A & \quad Se \\
B & \quad C
\end{align*} \]

were in themselves asymmetric, thus drawing a very sharp distinction between the optical activity of quadrivalent carbon and quadrivalent sulphur compounds.

The reluctance on the part of chemists to admit the existence of more than one type of valency bond in organic compounds prevented the development of Werner's hypothesis and hindered the recognition of its value. This is all the more unfortunate since his views could have been quickly put to experimental test. If it be asserted that the four valencies of the sulphur atom are not of equal value in the sulphine and thetine halogen compounds it necessarily follows that such is the case in all other compounds containing a quadrivalent sulphur atom. The question then immediately arises as to the equivalence of the four valencies of the sulphur atom in compounds in which the sulphur is attached to an oxygen atom, for example the sulphoxides. If the validity of
Werner's hypothesis be admitted such compounds cannot be represented by the generally accepted formula (I)

\[
\begin{align*}
  & R \quad S=O \\
  & R' \\
\end{align*}
\]

(II).  

Since no great difference has ever been detected experimentally between the two linkings by which the sulphur atom is united to the two carbon atoms of the groups \( R \) and \( R' \) it would be necessary to represent the sulphonides as (II). In this formula a distinction is made between the two remaining valencies by which the quadrivalent sulphur atom is united to the oxygen atom. In other words the sulphur-oxygen linking in these compounds is not a true double bond. We should therefore expect the sulphonide group to have a chemical character widely different from that of the ketonic group in which an oxygen atom is united to a carbon atom by two bonds of apparently equal value. These simple deductions are amply substantiated by experiment. The sulphonides do not show any of the properties of ketones: they do not condense with hydroxylamine or with phenylhydrazine: they cannot be reduced to compounds analogous to secondary alcohols and, furthermore, they are of a basic character, aliphatic sulphonides giving crystalline salts with nitric acid. It is therefore obvious that there is strong experimental support for the view that the nature of the sulphur-oxygen linking in sulphonides may differ considerably
from that of the carbon-oxygen linking in ketones. Having thus substantiated in some way the truth of formula II a further deduction can be made by taking into account the experimental work of Pope and Peachey. Viewed from the standpoint of Werner's hypothesis their results suggest that the three equivalent valency bonds of quadrivalent sulphur are directed along the three edges of a tetrahedron of which the sulphur atom occupies the apex. If, in spite of the sulphur and oxygen atoms being doubly linked, the molecule can adopt the tetrahedral configuration, it is obvious that the molecule, because of the unsymmetrical nature of the double bond which it contains, does not possess a plane of symmetry. It would therefore be expected that 'mixed' sulfoxides should be resolvable into enantiomorphous forms.

(b)

The Newer Electronic Theories of Valency.

Covalency and Electrovalency.

The electronic theories of atomic structure built upon the investigations of Sir J.J. Thomson, Lewis, Langmuir, Kossel and others were able, when applied to the problem of valency, to account for the difference between substances which are ionised in solution, such as sodium chloride, and
non-ionisable substances, such as carbon tetrachloride. By their aid two types of valency can be distinguished - *electrovalency*, in which an *atom* electron passes from the valency electronic shell of one atom, which it leaves with a positive charge, into the valency shell of the other atom to which it imparts a negative charge, and *covalency* in which the bond is formed by the sharing of two electrons, one of which is contributed by each atom. There is a great tendency on the part of atoms, when entering into combination with other atoms, to become surrounded by a ring or shell of *eight* valency electrons, called an 'octet', which is apparently the most stable configuration which can occur. It was first shown by Lowry (J., 1923, 123, 822) that since the electronic theories predict two types of the single bond, the double bond should exist in three distinct modifications:

1. The ordinary *NON-POLAR* form, consisting of two covalency bonds formed by the sharing of four electrons - two from each of the united atoms. Examples of this type of union are found in the molecules of ethylene and oxygen.

\[
\text{CH}_2 = \text{CH}_2, \quad \text{O} = \text{O}
\]

2. The *POLAR* type which occurs in ionisable compounds such as calcium sulphide, in which
the atoms are united by two electrovalency bonds. In this compound the calcium atom gives up the two electrons in its outermost shell to complete the octet of the sulphur atom which, in the neutral condition, has only six valency electrons in its outermost shell. By so doing the calcium atom gains two positive charges and imparts two negative charges to the sulphur atom.

\[ \text{Ca}^{2+} \quad \overset{\ddots}{\text{S}} \quad \rightarrow \quad \text{Ca}^{2+} \overset{\ddots}{\text{S}} \]

(3). The SEMI-POLAR type consisting of a 'mixed' double bond of one covalency and one electrovalency. The semi-polar bond is formed when one atom contributes both the electrons which are shared in the union, thereby acquiring a positive charge and imparting a negative charge to the atom with which it unites. Examples of the semi-polar double bond are to be found in triemethylamine oxide and many oxy-acids of sulphur and phosphorus:

\[(\text{CH}_3)_3\text{N}^+\ddot{\text{O}}, \quad \overset{\ddots}{\text{S}}(\ddot{\text{O}})\text{Cl}_2, \quad \overset{\ddots}{\text{P}}(\ddot{\text{O}})\text{Cl}_3.\]

\[\begin{array}{c}
\text{CH}_3 \quad \overset{\ddots}{\text{N}}^+ \ddot{\text{O}} \quad \overset{\ddots}{\text{P}}(\ddot{\text{O}}) \text{Cl}_2 \quad \text{Cl}_2 \quad \overset{\ddots}{\text{P}}(\ddot{\text{O}}) \text{Cl}_3
\end{array}\]
The Electronic Structure of Compounds containing Quadrivalent Carbon and Sulphur Atoms.

These considerations of valency from the standpoint of the electronic theories can now be applied to compounds of quadrivalent carbon and sulphur in which the central atom is attached in the first case to four different groups and secondly to three groups, one of which is united by a double bond.

In the case of a carbon compound:

\[
\begin{array}{c}
A & \text{D} \\
B & \text{C}
\end{array}
\]

the electronic configuration of the molecule is quite easily deduced. The neutral carbon atom possesses four valency electrons in its outermost shell and it is able to give one of these to be shared with one from each of the four mono-valent groups with which it unites. In this way four covalency bonds are produced.

\[
\begin{array}{c}
A & \text{D} \\
B & \text{C}
\end{array}
\]

The carbon atom remains surrounded by a stable octet of electrons. The formulation of ketones proceeds in a very similar way; four covalency bonds are again produced by the sharing of duplets of electrons and the oxygen atom is united to the carbon by two covalency bonds.
The neutral sulphur atom possesses six valency electrons in its outermost shell and if an attempt be made to formulate a compound containing a quadrivalent sulphur atom on the same lines as in the two examples just quoted, the sulphur atom is left with a surplus of valency electrons (ten instead of eight) as shown in III.

$$\begin{align*}
\ce{\cdot \cdot \cdot S \cdot \cdot \cdot} & \quad \ce{\cdot \cdot \cdot R' \cdot \cdot \cdot} \\
& \quad \ce{\cdot \cdot \cdot R \cdot \cdot \cdot} \\
& \quad \ce{\cdot \cdot \cdot O \cdot \cdot \cdot}
\end{align*}$$

(ten electrons surrounding the sulphur atom)

It is therefore evident that if the sulphur is united to two monovalent groups \( R \) and \( R' \) by covalency bonds (as in the organic sulphides) it is already in possession of its full complement of electrons (eight electrons) and that any further union effected with other elements must be accomplished without the addition of more electrons to the valency shell of the sulphur atom. Thus, the oxidation of a sulphide to a sulphoxide must be accomplished without the addition of more electrons to the valency shell of the sulphur atom. By the formation of a semi-polar bond, in which the sulphur atom contributes both the electrons to the duplet by which the atoms are joined, this compound can be formed.

$$\begin{align*}
\ce{\cdot \cdot \cdot R' \cdot \cdot \cdot S \cdot \cdot \cdot R \cdot \cdot \cdot} & \quad \ce{\cdot \cdot \cdot O \cdot \cdot \cdot}
\end{align*}$$

\( \ce{\cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot} \) is the sulphur electron which virtually becomes an oxygen electron.

Thus it is seen that the sulphoxides cannot be formulated as \( \ce{\cdot \cdot \cdot R' \cdot \cdot \cdot S \cdot \cdot \cdot R \cdot \cdot \cdot} \) since their electronic structure is quite different from the electronic structure of the ketones.
In the ketone molecule the double bond is symmetrical.
The formula for sulfoxides which the electronic theories suggest is therefore

\[ R' \overset{\dagger}{S} \overset{-}{\bar{O}} \]

in which the sulphur and sulphonyl oxygen atoms are united by an unsymmetrical semi-polar double bond.

Thus, the conclusion just reached on the basis of the newer electronic theories of valency that sulfoxides should be represented by the unsymmetrical formula \( R' \overset{\dagger}{S} \overset{-}{\bar{O}} \) is in complete agreement with the deduction previously made (page 22) from the classical theory of valency, that the chemical behaviour of these compounds is better represented by the unsymmetrical formula \( \overset{\bullet}{R} \overset{\bullet}{S} \overset{-}{\bar{O}} \)
Experimental Evidence of the Existence of the Semi-Polar Double Bond.

Experimental evidence of the existence of more than one type of double bond was first obtained as a result of the work on molecular volumes recently carried out by Sugden (J., 1928, 15, 1177). By using the relationship between surface tension and density which was discovered by Macleod (Trans. Faraday Soc., 1923, 10, 36) Sugden deduced an expression which was a function of the molecular volume and, moreover, was independent of the temperature. He called this function the 'Parachor' (P). The relation is represented by

\[ P = \frac{M}{D-d} \cdot \sigma^{\frac{1}{2}} \]

in which the symbols have their usual significance. From measurements of their surface tensions Sugden calculated the molecular parachors of a large number of chemical compounds of widely different types and by methods similar to those used for other physical properties he deduced the parachors of their constituent elements. Having obtained the parachors of the common elements he was able to proceed to the calculation of the parachors of compounds and the results obtained showed remarkable consistency: the margin of error between the calculated values and the values of the parachors found by experiment was very small indeed. The effect of certain constitutional factors is considerable and Sugden found that the value of the double bond between carbon and carbon, carbon and
oxygen and nitrogen and oxygen was in almost every case +23.2 units of parachor.

Shortly afterwards Sugden, Reed and Wilkins discovered (J., 1925, 127, 1525) that there was one very striking series of exceptions, in which the parachor of the double bond had the average value -1.6 units. The exceptions were the oxy-acids of sulphur and phosphorus and their derivatives and included such well known compounds as phosphorus oxy-chloride, sulphuryl chloride, diethyl sulphite and diethyl and dimethyl sulphates. The electronic theories of valency suggest that these compounds do not contain true double bonds and, according to Lowry (loc. cit.) should be formulated as containing semi-polar double bonds.

An explanation on physical grounds to account for the decrease in the molecular volume which accompanies the semi-polar double bond was put forward by Sugden. He supposed that the increase of +23.2 units was due to the extra volume required as a result of the mutual repulsion of the four electrons which are shared in the non-polar double bond, whilst the slight decrease, in the case of the semi-polar double bond (which may be assumed to be similar to the single covalency bond in its electronic configuration) was probably due to the mutual attraction of the opposite electrical charges which the two atoms bear.
The Asymmetry of Compounds of Quadrivalent Sulphur containing a Semi-Polar Double Bond.

(a). The n-Alkyl Esters of p-Toluenesulphinic Acid.

Additional strong experimental support for the existence of an unsymmetrical form of the double bond was afforded by the discovery by Phillips (J., 1925, 127, 2552) of the asymmetric character of the n-alkyl esters of p-toluenesulphinate. Phillips heated two equivalents of ethyl-p-toluenesulphinate with one equivalent of d-§-octanol and obtained a mixture of one equivalent of d-§-octyl-p-toluenesulphinate with one equivalent of ethyl-p-toluenesulphinate, as indicated in the equation:

\[ 2 \text{EtO}_2\text{SO}_2\text{C}_7\text{H}_7 + \text{C}_8\text{H}_{17}\text{OH} \rightarrow \text{EtO}_2\text{SO}_2\text{C}_7\text{H}_7 + \text{C}_8\text{H}_{17}\text{O}_2\text{SO}_2\text{C}_7\text{H}_7 + \text{EtOH} \]

The resulting mixture was fractionally distilled at very low pressures and the pure, liquid ethyl-p-toluenesulphinate isolated was found to be optically active. The optical activity shown by this ester cannot be accounted for by the formula:

\[ \text{EtO}_2\text{SO}_2\text{C}_7\text{H}_7 \]

by which its constitution is indicated by the classical theories of valency. Phillips therefore suggested that the formula

\[ \text{EtO}_2\text{S}^-\text{C}_7\text{H}_7 \]

in which the sulphur and sulphonxy oxygen atoms are united by a
semi-polar double bond, as required by the electronic theories of valency, would be more in accordance with its newly discovered property. This was substantiated experimentally by the determination of its parachor which was found to agree with the presence of a semi-polar double bond in the molecule of \textit{dl}-ethyl-\( p \)-toluenesulphinic ester.

The central atom is therefore attached to three dissimilar groups by covalency bonds and to one of them by an electrovalency.

In deciding the conditions which are necessary for the asymmetry of a compound in which the central atom is attached by covalency bonds to three dissimilar monovalent groups, Phillips suggested that the only other factor which was essential was the possession of a positive charge by the central atom. This condition was suggested by the failure of many workers to resolve compounds containing a tercovalent nitrogen atom which does not possess this positive charge (see Part III page 54). The 'lone pair' of electrons, which the sulphur atom retains is not considered by Phillips to be essential for the observed asymmetric character of the \( p \)-toluenesulphinic ester molecule.
(b). "Mixed" Sulphoxides.

The alternative formula for sulfoxides which was deduced in previous sections has now been substantiated by the resolution into their optically active forms of \( m \)-carboxy-phenylmethylsulphoxide and 4-amino-4'-methylidiphenylsulphoxide by methods which will be described later. Whilst the \( p \)-toluene-sulphinic esters described by Phillips were liquids and optically impure, the two sulfoxides mentioned are well defined crystalline substances of which both enantiomorphs have been obtained with \( [\alpha]_{5461}^25^\circ \sim 135^\circ \) in methyl alcoholic solution and \( [\alpha]_{5461}^25^\circ \sim 123^\circ \) in chloroform solution respectively.
The Preparation and Resolution of dl-m-Carboxyphenylmethylsulphoxide.

dl-m-Carboxyphenylmethylsulphoxide, m.p. 171-172°, was obtained by the oxidation in aqueous solution with hydrogen peroxide of the potassium salt of the corresponding thio-ether, m-carboxyphenylmethylsulphide (Smiles and Stewart, J., 1921, 119, 1792).

It was resolved into its enantiomorphous forms by recrystallisation of the salts formed with l-brucine and l-menthylamine and also by taking advantage of the very pronounced racemic character of the dl-form, which will be referred to later.

The salt formed with l-brucine was recrystallised from methyl alcohol until there was no further increase in its rotatory power. On decomposition dl-m-carboxyphenylmethylsulphoxide was obtained with $\left[\alpha\right]_{5461}^{25} + 125^\circ$ in methyl alcoholic solution. This product was not optically pure since by fractional recrystallisation from a mixture of chloroform and light petroleum, it was separated into two fractions with slightly slightly different rotatory powers. It was therefore combined with l-menthylamine and gave a salt with rotatory power $\left[\alpha\right]_{5461} + 66^\circ$ in ethyl alcoholic solution which was increased by three recrystallisations from acetone solution to $+69^\circ$, after which further recrystallisations produced no increase in the rotatory power. On decomposition the sulphoxide
was recovered with $[\alpha]_{5461}^{25^\circ} +137^\circ$ in methyl alcoholic solution.

The mother liquor from the first recrystallisation of the brucine salt containing the more soluble fractions was decomposed with normal sodium hydroxide solution and, after extraction of the brucine by chloroform and concentration, was acidified with concentrated hydrochloric acid. The sulphoxide which was precipitated was extracted with insufficient chloroform to effect its complete solution and the chloroform was filtered. The substance which remained undissolved had m.p. 170° and rotatory power $[\alpha]_{5461}^{50}$, whilst the portion which was precipitated from the chloroform by the addition of light petroleum had m.p. 133° and $[\alpha]_{5461}^{5461} +122^\circ$ in methyl alcoholic solution. Partial solution of this substance in chloroform did not lead to any increase in its rotatory power, showing that the chloroform was not the cause of the separation previously obtained. It appeared, however, that the precipitation of an optically impure sulphoxide from alkaline solution by the addition of a mineral acid favoured the formation of the $(\pm)$-compound which is maximally sparingly soluble in chloroform. That this explanation is substantially correct was proved by subjecting the sulphoxide with $[\alpha]_{5461}^{5461} -122^\circ$ twice to such treatment with alkali and acid: it was recovered from the final chloroform solution with $[\alpha]_{5461}^{5461} 25^\circ -133.5^\circ$. This value is almost equal (within the limits of experimental error) to that obtained for the dextrorotatory isomeride and a further repetition of the
process did not lead to any increase in the rotatory power.

The Preparation and Resolution of dl-4-Amino-4'-methyldiphenylsulphoxide.

dl-4-Amino-4'-methyldiphenylsulphoxide, m.p. 171°, was prepared by heating together p-toluenesulphinic acid and aniline according to the method described by Hinsberg (Ber., 1903, 36, 107) for the preparation of 4-aminodiphenylsulphoxide.

It was resolved by the recrystallisation of the salts which it forms with d- and with l-camphorsulphonic acids.

dl-4-Amino-4'-methyldiphenylsulphoxide was combined with d-camphorsulphonic acid with the formation of a salt which could be recrystallised from concentrated aqueous solution containing a small quantity of the acid without the obvious occurrence of hydrolysis. The d-camphorsulphonate obtained by continued recrystallisation of this salt was not optically pure. The sulphoxide recovered on decomposition had $\left[\alpha\right]_{D}^{5461} + 60^\circ$ in chloroform solution and on recrystallisation from aqueous ethyl alcohol the substance reached its maximum rotatory power with $\left[\alpha\right]_{D}^{25^\circ} + 123^\circ$ ($c=1.209$, $l=2.0$) in ethyl alcoholic solution and with $\left[\alpha\right]_{D}^{25^\circ} + 89.9^\circ$ ($c=1.279$, $l=2.0$) in chloroform solution.

The laevorotatory sulphoxide recovered from the mother liquors of the recrystallisation of the d-camphorsulphonate was combined with l-camphorsulphonic acid and the salt recrystallised from aqueous ethyl alcohol until its rotatory power remained
unchanged by further recrystallisation. On decomposition, 1-4-amino-4'-methyldiphenylsulphoxide was obtained with \( [\alpha]_{D}^{25^\circ} -122^\circ \) in ethyl alcoholic solution.

Determinations of the Rotatory Powers of d-m-Carboxyphenylmethylenesulphoxide and 1-4-Amino-4'-methyldiphenylsulphoxide.

The rotatory power of d,m-carboxyphenylmethylenesulphoxide was determined in solution in methyl alcohol, ethyl alcohol, chloroform and pyridine at 25° for light of wave lengths \( \lambda, 6708, 5893, 5461, 4359 \). The rotatory power of an aqueous solution of the sodium salt was also measured under the same conditions.

The values of the observed and specific rotatory powers are given in Table III, page 43.

The rotatory power of 1-4-amino-4'-methyldiphenylsulphoxide was determined in solution in ethyl alcohol, chloroform, pyridine and N. hydrochloric acid solution. It is of great interest to note that with 1-4-amino-4'-methyldiphenylsulphoxide as in the case of many other optically active compounds which contain an amino group, the sign of the rotatory power is reversed in hydrochloric acid solution. The values obtained are recorded in Table IV, page 44.
The Optical Rotatory Dispersive Powers of d-m-Carboxyphenylmethylsulphoxide and 1-4-Amino-4'-methylidiphenylsulphoxide.

Under the experimental conditions employed both d-m-carboxyphenylmethylsulphoxide and 1-4-amino-4'-methyldiphenylsulphoxide exhibit complex rotatory dispersion, since the rotatory powers will in no case fit a simple one-term Drude equation, but the complexity is least in the case of the chloroform solution of d-m-carboxyphenylmethylsulphoxide. It should be noted that this solvent is the one which is least likely to form a compound with the solute. It is difficult because of the relatively complex constitution of these compounds to ascribe the complex dispersion to any one particular factor, but it is very probably connected with their aromatic character and with solvent action accentuated by the presence of the semi-polar double bond. The dispersion ratio is unusually high \( \frac{\lambda \lambda_{4359}}{\lambda \lambda_{5461}} = 2 \) (approximately) in every case. This fact is also probably connected with the aromatic character of the compound. (In this connection compare Hewitt and Kenyon, J., 1925, 127, 1094.).
The Properties of the Optically Active Sulphoxides.

Mention must be made of several notable differences between the physical properties of the optically active sulphoxides and their inactive forms. Each of the compounds described exists in the inactive state as a well defined racemic compound of the \( \text{d-} \) and \( \text{l-} \) forms. The optically active forms, on the other hand, are apparently monomolecular and this difference in their molecular complexity is responsible for a considerable change in their physical properties. The most noticeable difference which occurs on resolution is in the melting point (nearly 40\(^\circ\) in the case of \( \text{d-m-carboxyphenylmethylsulphoxide} \)). There is also an increase in the solubility in certain solvents. For example, when saturated chloroform solutions of the \( \text{d-} \) and \( \text{l-} \) forms of \( \text{m-carboxyphenylmethylsulphoxide} \), m.p.133\(^\circ\), are mixed there is an immediate separation (to the extent of 85\%\) of the \( \text{dI-} \) compound which is only sparingly soluble. The occurrence of the \( \text{dI-} \) forms of the sulphoxides as racemic compounds is in marked contrast with the apparently monomolecular character of \( \text{dI-ethyl-p-toluene sulphinate} \) as shown by the measurement of its parachor. In contrast also with the racemisation of the \( \text{p-toluene sulphinic esters} \), which undergo fairly rapid \( \gamma \)ta-rotation on standing is the stability of the asymmetry of the sulphoxides: solutions have been kept for some time without undergoing any racemisation. It is not considered
however, that the experiments so far attempted have been of sufficiently searching a character to detect a possible very slow muta-rotation. The only instance of racemisation occurred when \( d\rlap{-}m\rlap{-}c\rlap{-}arboxyphenylmethylysulphoxide \) was warmed with concentrated hydrochloric acid for a few moments. It is well known that compounds such as

\[
\begin{align*}
R' & \quad \text{and} \quad R' \\
S' & \quad \text{and} \quad S'
\end{align*}
\]


\( \text{can be formed by the sulfoxides with halogens and halogen acids and it is possibly due to such changes that the racemisation occurs. Mention must also be made of certain experimental difficulties encountered in the recovery of } d\rlap{-}m\rlap{-}c\rlap{-}arboxyphenylmethylysulphoxide \text{ from its } l\rlap{-}brucine \text{ salt. This apparent loss of sulfoxide may possibly be due to the substance undergoing isomerisation leading to decomposition, which may be the counterpart in this compound of the mutarotation of the sulphinic esters. The dynamic isomerism of benzyl sulfoxide has been studied by Smythe (J., 1909, 95, 349), whilst Pummerer (Ber., 1909, 42, 2282) discovered that both phenyl and } p\rlap{-}tolylsulphoxyacetic \text{ acids were easily decomposed by mineral acids with the formation of the corresponding thiols and glyoxylic acid.}

In view of the unsatisfactory yield of \( d\rlap{-}m\rlap{-}c\rlap{-}arboxyphenylmethylysulphoxide \) (about 25% of the quantity combined in the salt) which was obtained when the \( l\rlap{-}brucine \) salt was decomposed
decomposed in aqueous solution by means of sodium hydroxide, an investigation of the salt was undertaken by titrating it with alkali under varying experimental conditions. The investigation showed that it was only when the salt was titrated with the alkali in a 50% aqueous solution of ethyl alcohol that it reacted with the calculated quantity of alkali. It was then found that if the decomposition of the brucine salt were carried out under the same conditions in the presence of alcohol a satisfactory yield of the sulphoxide (80%) could be obtained. An attempt will be made to suggest an explanation which is in accordance with these observed experimental facts. Evidence has been brought forward to show that in the optically active condition the sulfoxides are probably monomolecular.

Racemic compound, dl. Monomolecular d- or l-

In the monomolecular condition the molecule can conceivably become hydrated with the formation of the compound III.
Under conditions which might lead to ionisation (such as aqueous solution) this compound might pass into the dehydrated form IV, which would not react with the alkali, whilst, on the other hand, if no ionisation occurred (such as in ethyl alcoholic solution) there would be little tendency to form the compound IV and the substance would react in the form III with the calculated amount of alkali.
### TABLE III

Determinations of the Rotatory Power of d-m-carboxyphenylmethylsulphoxide m. p. 133°

<table>
<thead>
<tr>
<th>Solvent</th>
<th>G. of Solute in 100 c.c.</th>
<th>l in mm.</th>
<th>6708</th>
<th>5893</th>
<th>5780</th>
<th>5461</th>
<th>4359</th>
<th>6708</th>
<th>5893</th>
<th>5790</th>
<th>5461</th>
<th>4359</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methyl alcohol</td>
<td>2.515</td>
<td>100</td>
<td>+2.17</td>
<td>+2.87</td>
<td>+2.98</td>
<td>+3.46</td>
<td>+6.95</td>
<td>+86.3</td>
<td>+114</td>
<td>+118</td>
<td>+137</td>
<td>+276</td>
</tr>
<tr>
<td>Chloroform</td>
<td>1.265</td>
<td>200</td>
<td>2.92</td>
<td>4.07</td>
<td>4.32</td>
<td>5.02</td>
<td>10.11</td>
<td>115</td>
<td>161</td>
<td>171</td>
<td>198</td>
<td>400</td>
</tr>
<tr>
<td>Ethyl alcohol</td>
<td>2.515</td>
<td>100</td>
<td>2.24</td>
<td>3.09</td>
<td>3.19</td>
<td>3.77</td>
<td>7.68</td>
<td>89</td>
<td>123</td>
<td>127</td>
<td>150</td>
<td>306</td>
</tr>
<tr>
<td>Pyridine</td>
<td>2.515</td>
<td>100</td>
<td>2.44</td>
<td>3.25</td>
<td>3.46</td>
<td>4.04</td>
<td>8.34</td>
<td>97</td>
<td>129</td>
<td>137</td>
<td>161</td>
<td>232</td>
</tr>
</tbody>
</table>

**Determination of the Rotatory Power of the sodium salt of d-m-carboxyphenylmethylsulphoxide**

| Water        | 2.520                   | 100      | 1.70  | 2.42  | 2.56 | 3.00 | 5.98 | 67.5 | 96   | 102  | 119  | 237  |

*This solution was prepared by diluting to the required volume a solution of a known weight of the d-sulphoxide in the calculated quantity of standard sodium hydroxide.*
<table>
<thead>
<tr>
<th>Solvent</th>
<th>G. of solute in 100 c.c. of soln.</th>
<th>$\chi_{25^\circ}$ observed</th>
<th>$[\chi]_{25^\circ}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chloroform</td>
<td>1.2580</td>
<td>-1.30 -1.76 -2.23 -4.71</td>
<td>-51.7 -70.0 -88.6 -187.2</td>
</tr>
<tr>
<td>Ethyl alcohol</td>
<td>1.2110</td>
<td>1.83 2.35 2.95 6.17</td>
<td>75.6 97.1 122 255</td>
</tr>
<tr>
<td>Pyridine</td>
<td>1.3375</td>
<td>2.52 3.37 4.21 8.97</td>
<td>94.2 126 157 335</td>
</tr>
<tr>
<td>1.04M hydrochloric acid</td>
<td>1.2430</td>
<td>+0.69 +0.86 +1.16 +2.19</td>
<td>+27.7 +34.6 +46.7 +88.1</td>
</tr>
</tbody>
</table>
PART III

THE OPTICAL PROPERTIES OF d-\(\beta\)-OCTYLPHENYL CARBAMATE.

In Part I it was stated that the complex rotatory dispersion shown by a large number of the esters formed from carboxylic acids and aliphatic secondary alcohols was considered to be associated with the presence of the carboalkyloxy group, and that since this phenomenon is believed to arise from the presence in the optically active compounds of more than one "rotatory electron", two isodynamic forms of the ester have been suggested (Pickard and Kenyon, J., 1914, 105, 830).

This hypothesis was not based on any chemical evidence and it is difficult to understand how these very similar forms can sometimes have rotatory powers of opposite sign which must be assumed in order to explain the occurrence of anomalous dispersion among the esters under the appropriate experimental conditions.

Recently Phillips (J., 1925, 127, 2552) has suggested another mechanism to explain the complex rotatory dispersion of carboxylic esters, in which he postulates the existence of two labile forms with opposite configurations which are easily interconvertible through the true ketonic form.
In I and III the carboxylic ester grouping is asymmetric and the conception is similar to the "induced asymmetry" of the ketonic group suggested by Lowry and Walker (Nature 1924, 113, 565). This explanation was adapted by Phillips from a somewhat similar scheme with the aid of which he explained the muta-rotation of the p-toluenesulphinic esters of optically active alcohols.

An experiment undertaken in an attempt to separate the isomeric forms of the carboxylic esters, if they should exist, was described by Lowry (J. 1921, 21, 531) who fractionally distilled at low pressures a large quantity of very carefully purified di-ethyl-tartrate. The fractions which he obtained were, however, of identical rotatory power in every case, showing that no separation had occurred under the conditions of the experiment.

Since the failure to separate ethyl tartrate by distillation into fractions with different physical properties did not necessarily indicate the non-existence of labile isomeric forms, it was decided to try a similar experiment with esters of another type.

For this investigation the esters chosen were the urethanes. The urethanes were decided upon because, as will now be shown, an examination of the generally accepted formula for these compounds suggests the possibility of several alternative labile and possible asymmetric modifications.

Possible Isomeric Forms of the Urethanes.

It has been shown by E.A. Werner (J., 1914, 105, 23; et seq.),
from a careful quantitative study of the behaviour of urea when treated with nitrous acid, that the experimental results are more in accordance with an alternative cyclic formula for this compound than with the usually accepted carbamide formula. This formulation readily explains why urea forms salts with only \textit{one} molecule of an acid, since the following molecular rearrangement may occur

\[
\text{HN} = \text{CO}_2 \rightleftharpoons \text{NH}_3 + \text{HCl} \rightarrow \text{HN} = \text{CO}_2 \rightleftharpoons \text{NH}_2 \cdot \text{HCl}
\]

Furthermore, as Plimmer has recently confirmed (\textit{J.}, 1925, 127, 2651), the cyclic formula also explains the observation that nitrous acid will only liberate nitrogen from urea in the presence of strong mineral acids and not in the presence of weak acids such as acetic acid, which are unable to cause the molecular rearrangement described. If the carbamide formula were correct the decomposition of urea by nitrous acid should produce nitrogen and carbon dioxide in the proportion of two volumes of nitrogen to every volume of carbon dioxide:

\[
\text{CO} \left\{ \begin{array}{c} \text{NH}_2 \\ \text{NH}_2 \end{array} \right\} + 2 \text{HONO} \rightarrow 2 \text{N}_2 + 3 \text{H}_2 \text{O} + \text{CO}_2
\]

whereas experiment shows that these gases are evolved in approximately equal proportions.

Langmuir has suggested a slight modification of the cyclic formula based on the 'octet' theory:

\[
\text{HN} = \text{C} \rightleftharpoons \text{NH}_3
\]
Similar modifications of the formula for the urethanes might be possible. For example ethylphenyloarbamate might exist as

\[
\text{EtO} \equiv \text{N} \equiv \text{C}_{6}\text{H}_{5} \quad \text{OH}.
\]

Other formulations involving electrovalencies between the carbon, nitrogen and oxygen atoms can be deduced by applying the electronic theories of valency.

\[
\begin{align*}
\text{EtO} & \equiv \text{C} \equiv \text{N} \equiv \text{C}_{6}\text{H}_{5} \\
\text{EtO} & \equiv \text{C}^{+} \equiv \text{N} \equiv \text{C}_{6}\text{H}_{5} \\
\text{EtO} & \equiv \text{C} \equiv \text{N}^{+} \equiv \text{C}_{6}\text{H}_{5} \\
\text{EtO} & \equiv \text{C} \equiv \text{N} \equiv \text{C}_{6}\text{H}_{5} \\
\text{EtO} & \equiv \text{C} \equiv \text{N} \equiv \text{C}_{6}\text{H}_{5}
\end{align*}
\]

Each of these forms, which are predicted by the application of the newer electronic theories of valency, will now be considered in detail.

(1). This represents the usually accepted formula for the urethanes and is the form most likely to occur. The electronic structure which can be given to it is as follows:

\[
\text{EtO} \equiv \text{C} \equiv \text{N} \equiv \text{C}_{6}\text{H}_{5}
\]
The nitrogen atom is attached to three different groups by covalency bonds and such a system might be asymmetric although, as will be shown later, all attempts to resolve such a structure have so far failed.

(2). This structure is formed by the opening of the double bond and may be compared with the induced asymmetry of the ketonic group suggested by Lowry (loc. cit.).

\[
\text{EtO} + C + N + C_6H_5
\]

(3). The electronic structure of (2) suggests that it would probably be unstable since the central carbon atom is surrounded by a sextet instead of a stable octet of electrons. The carbon atom will endeavour to complete an octet of electrons and will do this either by reverting to the structure shown in (1), or by securing the lone pair of electrons carried by the nitrogen atom with the formation of structure (3).

\[
\text{EtO} + C + N + C_6H_5
\]

In (3) the carbon atom is united to the nitrogen atom by a true double bond and an electrovalency is exerted between the nitrogen and the oxygen atoms. Such a structure would probably be stable.
(4). The structure (4) is obtained by a process similar to the formation of (3). In order to produce (4) the carbon atom completes its octet at the expense of two of the electrons which surround the oxygen atom of the ethoxy group, with which it forms a double bond. The electronic configuration of the positively charged oxygen atom is very similar to the electronic configuration of the sulphur atom in the sulfoxides.

\[ \text{EtO}^+ \quad \text{Et} \quad \text{C} \quad \text{N} \quad \text{C}_6\text{H}_5 \]

(5). This is another structure which can be formulated. It is probable that, if this compound could exist, both the carbon and nitrogen atoms would be asymmetric.
The Possible Asymmetry of the Urethanes.

Many unsuccessful attempts have been made to resolve substances of the type R'R"R"N, in which the nitrogen atom is tercovalent. Reyschler (Bull. Soc. chim., 1902, 27, 979) failed to resolve naphthylmethylethylamine whilst Jones and Millington (Proc. Camb. Phil. Soc., 1904, 12, 489) were unsuccessful in their attempt to resolve the d-camphorsulphonate of phenylbenzyl-hydrazine, in which the optically active molecule is not directly attached to the nitrogen atom concerned. These workers also attempted the resolution of methylethylanilinesulphonic acid by means of l-brucine. The above, together with other fruitless attempts led Meisenheimer (Ber., 1923, 56, 1353) to the conclusion that a molecule containing three dissimilar groups united by covalency bonds to a tercovalent nitrogen atom is not asymmetric. No satisfactory explanation, however, has been given to account for the supposed symmetry of such a molecule.

The experiments described in this section constitute an entirely new method of attack upon the problem. The method used by Phillips for the preparation of optically active esters of p-toluenesulphinic acid has been applied to ethylphenyl-carbamate, and d-β-octylphenylcarbamate has also been fractionally distilled without change of rotatory power. Such experiments should prove successful where others might fail, since the possible interference which might be caused by the introduction of an optically active acid and the complicating
effect of the solvent are entirely removed.

The results obtained from these experiments appear to justify Meisenheimer's hypothesis that a compound containing a tercovalent nitrogen atom attached to three different groups is symmetrical.
The Methods employed to detect the Possible Isomerism of the Urethanes.

If any of the various alternative forms which have been suggested should exist in the urethanes their presence could be indicated by the separation of these compounds by distillation into fractions with different physical properties, or by the occurrence of mutarotation in a freshly distilled optically active urethane such as d-β-octylphenylcarbamate. To investigate these possibilities two series of experiments were undertaken; the first consisted in heating together under varying experimental conditions a mixture of two molecular proportions of ethylphenylcarbamate (phenylurethane) with one molecular portion of d-β-octanol and after the alcohol exchange had been completed the mixture of d-β-octylphenylcarbamate and ethylphenylcarbamate was separated by fractional distillation at low pressures; thus if ethylphenylcarbamate were able to exist in the optically active or isodynamic forms previously indicated the product might have physical properties different from those of the original material. The second experiment was the slow distillation at very low pressures of a quantity of d-β-octylphenylcarbamate with a view to its separation into fractions with different physical properties, indicating a separation of the possible isomeric forms of this compound.
Experiment I.

\[ \text{d-}^{\beta}\text{-octanol (1 mol.) reacted with ethylphenylcarbamate (2 mols.) when the substances were heated together at 175° for 24 hours, with displacement of one molecular amount of ethyl alcohol.} \]

\[ 2 \text{EtCO.NH.C}_6\text{H}_5 + \text{d-C}_8\text{H}_{17}\text{OH} \rightarrow \text{EtO.CO.NH.C}_6\text{H}_5 + \text{EtOH} \]

\[ + \text{d-C}_8\text{H}_{17}\text{O.CO.NH.C}_6\text{H}_5. \]

The ethylphenylcarbamate (1 mol.) which remained after was separated by fractional distillation at low pressures and after the d-\(\beta\)-octylphenylcarbamate, by which it was at first contaminated, had been removed by systematic re-fractionation it was found to be optically inactive. Although d-\(\beta\)-octylphenylcarbamate obtained from d-\(\beta\)-octanol is dextrorotatory a quantity of ethylphenylcarbamate which, before refractionation, contained a small amount of d-\(\beta\)-octylphenylcarbamate was found to be laevo-rotatory. This led to a determination of the rotatory powers of mixtures of ethyl and d-\(\beta\)-octylphenylcarbamates. The behaviour of d-\(\beta\)-octylphenylcarbamate in solution in ethylphenylcarbamate was found to be very similar to the behaviour of d-\(\beta\)-octyl acetate in solution in carbon disulphide, in which the sign of the rotatory power is also reversed: solution in carbon disulphide does not, however, cause a reversal of the sign of the rotatory power of d-\(\beta\)-octylphenylcarbamate, although the solution shows complex rotatory dispersion.
The results of this investigation of the rotatory powers of mixtures of the two substances are given on page 61 in a table showing the observed rotatory powers of solutions of \( \alpha \)-\( \beta \)-octylphenylcarbamate in ethylphenylcarbamate (\( \alpha = 0.5 \)). If these values are plotted as specific rotatory powers vs curves are obtained which show clearly the conditions of concentration necessary for the production of anomalous rotatory dispersion. This phenomenon arises when \( \alpha \)-\( \beta \)-octylphenylcarbamate is mixed with a small amount (10%) of ethylphenylcarbamate. The refractive indices of the various solutions are shown.

All the mixtures remained supercooled for a sufficient length of time for their refractive indices at 25\( ^0 \)C to be measured, even that containing only 3% of \( \alpha \)-\( \beta \)-octylphenylcarbamate.

**Experiment II**

The careful fractional distillation of a large quantity of \( \alpha \)-\( \beta \)-octylphenylcarbamate was carried out in an apparatus similar to the one used in the last experiment, but it was not possible to detect any variation in the physical properties of the fractions obtained. There was also no
From the results of the two series of experiments which have been described it is evident that if labile isomeric (and possibly asymmetric) forms of the urethanes exist they are not capable of separation by the methods of alcohol exchange or fractional distillation. The occurrence of complex rotatory dispersion in the rotatory power of 1-β-octyl-phenylo-carbamate appears at first sight to indicate that two forms of the optically active ester may possibly exist, but, on the other hand, the phenomenon may be due entirely to the presence in the molecule of the benzene structure.
Determinations of the Density of \( \text{d-}\beta\text{-Octylphenylcarbamate} \).

The determinations of density were carried out in a pyknometer of about 2 c.c. capacity, previously calibrated with water. The values obtained for the density at the three different temperatures at which determinations were made lie on a straight line when plotted against the corresponding temperatures.

\[
\text{Density at } t^\circ \text{ with respect to water at } 4^\circ :-
\]

\[
\begin{array}{|c|c|c|c|}
\hline
\text{t}^\circ & 20.5^\circ & 42.3^\circ & 65.0^\circ \\
\hline
\text{d}_4 & 0.9979 & 0.9815 & 0.9638 \\
\hline
\end{array}
\]

The Physical Properties of \( \text{d-}\beta\text{-Octylphenylcarbamate} \) mixed with about 10% of \( \text{Ethylphenylcarbamate} \).

\[
\begin{array}{|c|c|c|c|}
\hline
\lambda & 4359 & 5461 & 5893 & 6708 \\
\hline
25^\circ & +0.24^\circ & +0.30^\circ & +0.40^\circ & +0.32^\circ \\
\hline
\end{array}
\]

Indicating anomalous rotatory dispersion.

\[
\begin{array}{c|c}
25.2^\circ & n \text{ 5893  1.5083} \\
\hline
\end{array}
\]
Observed Rotatory Powers of Solutions of d-β-Octylphenylcarbamate in Ethylphenylcarbamate.

<table>
<thead>
<tr>
<th>% Octyl in Ethyl-</th>
<th>3.8</th>
<th>7</th>
<th>12</th>
<th>50</th>
<th>75</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \lambda ) 4359</td>
<td>-0.44°</td>
<td>-0.50°</td>
<td>-0.80°</td>
<td>-0.80°</td>
<td>+0.34°</td>
<td>+1.12°</td>
</tr>
<tr>
<td>( \lambda ) 5461</td>
<td>-0.23°</td>
<td>-0.32°</td>
<td>-0.45°</td>
<td>-0.25°</td>
<td>+0.40°</td>
<td>+0.98°</td>
</tr>
<tr>
<td>( \eta ) 5893</td>
<td>1.5375</td>
<td>1.5346</td>
<td>1.5317</td>
<td>1.5203</td>
<td>1.5140</td>
<td>1.5063</td>
</tr>
</tbody>
</table>
PART I

EXPERIMENTAL

THE PREPARATION AND OPTICAL PROPERTIES OF d-sec.-BUTYLBENZENE.

β-Phenyl-β-butylen.

By the interaction of ethylmagnesium bromide (5 mols.) and acetophenone (4 mols.) methylethylphenylcarbinol was obtained as a yellowish oil which decomposed on distillation under atmospheric pressure, yielding β-phenyl-β-butylen, b.p. 180-195°. Yield 75% of theory. Ethyl bromide can be prepared in large quantities by the method described in "Organic Syntheses" Vol. 1, page 6. As an alternative it was convenient to use ethylmagnesium chloride which was prepared by bubbling ethyl chloride into ether covering magnesium turnings until the requisite decrease in the weight of the ethyl chloride container was produced.

dl-sec.-Butylbenzene

β-Phenyl-β-butylen was reduced in boiling ethyl alcoholic solution by means of sodium. It was found that 100% alcohol was not essential for the reduction, but that alcohol of about 99% purity (96% refluxed with and distilled from quicklime) was in every way satisfactory. It was further found
that the quantity of sodium necessary for the reduction of 200 g. of the unsaturated hydrocarbon could be decreased from 200 g. quoted by Mr Shepherd (loc. cit.), to 140 g. without any appreciable decrease in the yield obtained. In this way 635 g. of dl-sec.-butylbenzene, b.p. 166-173 ° were prepared, the yield being 87% of the theoretical.

dl-p-Nitro-sec.-butylbenzene.

The nitration of dl-sec.-butylbenzene was carried out using batches of 200 g. of the hydrocarbon in a three litre round bottom flask fitted with a very efficient mechanical paddle stirrer. The flask was cooled in an ice bath and a mixture of nitric acid (128 c.c.; d-1.42) and sulphuric acid (160 c.c.; d 1.84) was gradually added with vigorous stirring to the ice-cold hydrocarbon. The temperature of the reaction mixture was maintained at 15-20 ° and the time required for the addition of the nitrating mixture was about 3½ hours, after which stirring was continued for half an hour until the fall in the temperature of the mixture indicated the completion of the reaction. The product was poured into five litres of water with thorough stirring. The heavy nitro compound was separated, diluted with twice its volume of ether, the ethereal extract washed three times with sodium carbonate solution and again three times with water and finally dried over calcium chloride after which the ether was removed. Very careful washing was essential
in order to remove all traces of acids which, if present, caused decomposition to occur during the subsequent distillation. The mixture of \textit{dl-p-nitro-sec.}-butylbenzene and the other isomerides of nitration was distilled under reduced pressure. It was not possible to effect the removal of the relatively small proportion of the other isomerides which was present by fractional distillation because the distillate could not be separated into any well defined fractions. The portion which distilled between 130° and 147°/16mm. was collected and used for the preparation of the corresponding amine.

\textit{dl-p-Amino-sec.}-butylbenzene.

\textit{dl-p-Nitro-sec.}-butylbenzene (150 g.) was heated on a water bath with concentrated hydrochloric acid (570 c.c.) and granulated tin (200 g.) in a two litre round bottom flask fitted with an air condenser five feet long; the slow reaction which soon commenced suddenly became violent when the concentration of the stannous chloride reached a certain value. On cooling a solid mass of the stannichloride of the amine separated. Recrystallisation of this compound from dilute hydrochloric acid solution was without effect on its melting point and hence it was assumed that the other isomerides were not removed from the mixture by this process. The mixture was accordingly made alkaline with sodium hydroxide solution and the amine
removed in a current of steam. dl-p-Amino-sec.-butylbenzene prepared in this way had b.p. 118°/15mm. and d 4° 0.049.

Purification of the Amine.

This was accomplished by the recrystallisation of the salt formed by the mixture of the dl-p- and the other isomeric amines (probably the ortho with a small amount of the meta) with excess of oxalic acid, a method used by Rosenstiehl (Bull. Soc. chim., 177) for the separation of the toluidines. The mixed salts, which were obtained, were shown by titration to be the neutral oxalates. The progress of the separation was closely followed by observations of the density of the amines recovered from the crops and filtrates obtained during the recrystallisation of the salts. The amine recovered from the filtrate from the first recrystallisation had d 15° 0.961, whilst that obtained from the second crop and considered to be the pure para isomeride had d 15° 0.949. It is of interest to notice the parallel case of amino-tert.-butylbenzene; the density of the para amine is d 15° 0.977, whilst for the ortho isomeride it is d 15° 0.9525. (Senkowski, Ber., 23, 246).
The Resolution of dl-$\beta$-Amino-sec.-butylbenzene (dl-$\beta$-sec.-butylaniline)

It was found after the commencement of this investigation that Glattfeld and Wertheim (J. Amer. Chem. Soc., loc. cit.) had attempted the resolution of dl-$\beta$-sec.-butylaniline by recrystallisation of the salt obtained with $\alpha$-camphorsulphonic acid. The results which they obtained have been mentioned in the theoretical portion of this thesis.

Of the optically active acids employed in the resolution now described, $\alpha$-tartaric acid, the most readily accessible optically active acid, was tried at first and subsequently proved to be the most successful. $\alpha$-camphorsulphonic acid was tried at later stages, as will be mentioned, but it was not found to be of much assistance; $\beta$-malic acid could not be induced to form a crystalline salt; $\alpha$-camphoric acid gave a well defined crystalline salt but recrystallisation of this salt did not effect any resolution of the amine.

The salts obtained were recrystallised from water, ethyl alcohol and acetone, but of all the attempts made, the recrystallisation of the $\alpha$-hydrogen tartrate of the amine from its solution in hot water was easily the most successful.

An unsuccessful attempt was also made to resolve the amine by means of $\alpha$-oxymethylene camphor, which was employed by Pope and Read (J., 1913, 103, 451 and J., 1909, 95, 172) in the resolution of dl-$\alpha$-phenylethylamine. dl-$\beta$-Amino-sec.-
butylbenzene (7.5 g.) was dissolved in 15 c.c. of 30% acetic acid and mixed with a solution of d-oxymethylenecamphor (10 g.) in warm methyl alcohol. The mixture was cooled and soon deposited a heavy crystalline precipitate. This was removed by filtration. The amine was recovered from the filtrate by the addition of bromine water to decompose the compound and distillation of the amine in a current of steam after the addition of caustic soda solution. The amine obtained from this filtrate and also from the crop after a second recrystallisation was found in each case to be optically inactive.

Preparation and Recrystallisation of the d-hydrogen tartrate of dl-p-Amino-sec.-butylbenzene.

dl-p-Amino-sec.-butylbenzene (285 g.) was added to a boiling solution of d-tartaric acid (300 g.) in water (1100 c.c.). A salt crystallised on cooling in the form of very fine prismatic rods; it was shown by titration with standard N/10 caustic soda solution to be the d-hydrogen tartrate. 0.3033 g. of the salt required 18.2 c.c. of caustic potash solution (1063 N/10) for complete neutralisation (phenolphthalein as indicator). It was calculated that if the salt were the neutral tartrate it would require 12.7 c.c. whilst the hydrogen tartrate would require 19.1 c.c.

The salt was occasionally deposited as a wax-like mass,
which changed to the usual form of crystalline rods on standing for a short time. It was submitted to a long course of systematic recrystallisation until successive crops on decomposition yielded the amine with the same rotatory power. About thirty recrystallisations of the main crop were required before it was ascertained that no further increase in the rotatory power could be produced. This process was naturally very wasteful and the amount of amine obtained by the decomposition of all the salt of maximum activity was only ten grams.

The Recovery of d-p-Amino-sec.-butylbenzene from its Salts with Optically Active Acids.

The method adopted in all cases was as follows: The salt was dissolved in water and a slight excess of caustic soda solution added. The amine soon separated as an oil which rose to the surface of the liquid and was removed by distillation in a current of steam. The amine was almost insoluble in water and was separated in a funnel and dried with potassium carbonate. It was sufficiently clear and colourless for polarimetric observation without any further treatment.

Since the optically active amine prepared by this method could be converted into a salt and recovered therefrom with identical rotatory power no racemisation occurred during its isolation.
The amine recovered from the final crops was distilled under reduced pressure and had $\alpha J_{5461}^{20^\circ} +40.98^\circ$, b.p. $114^\circ/12$mm. and $\alpha_2^{20^\circ} 0.9449$.

The course of the resolution is shown by the following values of the rotatory power ($\frac{\alpha}{\alpha}=1.0$) of the amine recovered from some of the crops:

<table>
<thead>
<tr>
<th>Number of recrystallisations of the amine</th>
<th>Observed rotatory power of $\alpha$-hydrogen tartrate of the amine.</th>
</tr>
</thead>
<tbody>
<tr>
<td>four</td>
<td>$+16^\circ$</td>
</tr>
<tr>
<td>eight</td>
<td>23</td>
</tr>
<tr>
<td>twelve</td>
<td>28</td>
</tr>
<tr>
<td>sixteen</td>
<td>31</td>
</tr>
<tr>
<td>twenty-two</td>
<td>37</td>
</tr>
<tr>
<td>twenty-five</td>
<td>38.2</td>
</tr>
<tr>
<td>twenty-seven</td>
<td>38.7</td>
</tr>
<tr>
<td>thirty</td>
<td>3877</td>
</tr>
</tbody>
</table>
Attempts to Prepare 1-p-Amino-sec.-butylbenzene.

Various attempts were made to prepare the optically pure form of the laevorotatory isomeride, but without success. Some laevorotatory amine with specific rotatory power $\left[\alpha\right]_D^{20°} = -20°$ was recovered from the mother liquors during the resolution. The $d$-camphorsulphonate of this amine was prepared and recrystallised several times from water, ethyl alcohol and acetone, but the increase in the rotatory power thus produced (3° for three recrystallisation) was so small that the method was abandoned. Small quantities of the laevorotatory amine were also converted into the normal oxalate and the hydrochloride but the rotatory powers of these salts remained unchanged after recrystallisation.
Preparation of dl-p-Acetamino-sec.-butylbenzene.

*dl*-p-Acetamino-sec.-butylbenzene was prepared by the careful addition of acetic anhydride (Kahlbaum's, 0.4 g.) to the amine (0.5 g.). The mixture became very hot and was kept at 100° for ten minutes. On pouring into cold water a solid separated which was broken up, filtered and washed well with cold water. It was recrystallized twice from warm 50% ethyl alcohol. After drying in a desiccator for two days the crystals had m.p. 123° (Reilly and Hickinbottom quote 125° as the melting point of *dl*-p-sec.-butylacetanilide, J., 1920, 117, 120).

Preparation of d-p-Acetamino-sec.-butylbenzene.

The acetyl derivative of the optically active amine was prepared in the manner just described. It had m.p. 124°.

The rotatory power of d-p-Acetamino-sec.-butylbenzene was determined in 5% solution in chloroform. The values are shown in the Table on Page 18.
d-sec.-Butylbenzene.

By diazotising a solution of d-p-amino-sec.-butylbenzene in hydrochloric acid with sodium nitrite solution and treating the solution of d-sec.-butylbenzenediazonium chloride with a strongly alkaline solution of sodium stannite, d-sec.-butylbenzene was obtained. (Compare Friedländer, Ber., 1889, 22, 587).

$\text{d-P-Amino-sec.-butylbenzene (6 g.) with } [\alpha]_{D}^{20} + 40.98^{\circ} \text{5461} \equiv \text{d-P-Butylbenzene}$

was placed in a 500 c.c. round bottom flask fitted with an efficient paddle stirrer and thermometer. The flask was cooled in an ice-salt freezing mixture. Powdered ice (12 g.) and concentrated hydrochloric acid were then added and, after the temperature had fallen to -5°, a solution of potassium nitrite (4.2 g.) in water (8 c.c.) was run in slowly from a tap funnel. During the addition of the nitrite solution a precipitate was formed which redissolved on further stirring. The temperature was allowed to rise to +2° in order to complete the diazotisation. The reducing solution was prepared by adding strong caustic soda solution to a solution of stannous chloride (18 g.) in water (45 c.c.) until the bulk of the black precipitate which at first formed was redissolved. This solution was then added very rapidly to the solution of the diazotised amine: there was a vigorous evolution of nitrogen and the characteristic odour of the hydrocarbon became apparent. d-sec.-Butylbenzene was distilled from the reaction flask in a current of steam; it was collected, separated from the aqueous layer by extraction
with ether, the ether solution dried with calcium chloride, the solvent removed on a water bath and the hydrocarbon distilled.

A fraction (2 g.) representing a yield of 40% was collected at 171-172°; it had $d_4^0 = 0.8639$ and $[\alpha]^2_{5461} = +33.15°$.


The rotatory power of the amine was determined in the homogeneous state and in solution in ethyl alcohol, chloroform and carbon disulphide at a concentration of 5%. The rotatory power of the acetyl derivative of the d-amine was determined in chloroform solution. The rotatory power of d-sec.-butylbenzene was determined in the homogeneous state. All the determinations were made at 20°. The results are recorded in Table II, Page 18.
EXPERIMENTAL

THE RESOLUTION OF SULPHOXIDES INTO THEIR OPTICALLY ACTIVE FORMS.

(a) dl-m-Carboxyphenylmethylsulphoxide.

m-Chlorosulphonylbenzoic Acid.

Benzoic acid (300 g.) was added to chlorosulphonic acid (1440 g.) and the mixture heated to 125° for 1½ hours when the copious evolution of fumes ceased. After cooling, the liquid was poured on a large quantity of ice when m-chlorosulphonylbenzoic acid separated as a yellowish-white solid. It was filtered, washed with water and dried and had m.p. 122° and 131° after recrystallisation from hot benzene. (Compare Smiles and Stewart, J., 1921, 119, 1792). In subsequent experiments in which 'water-white' redistilled chlorosulphonic acid was used, the product was obtained with m.p. 134-135°.

m-Thiolbenzoic Acid.

m-Chlorosulphonylbenzoic acid (60 g.) was dissolved in warm glacial acetic acid (300 c.c.) and the solution heated on a water bath. Zinc dust (240 g.) together with sufficient concentrated hydrochloric acid to maintain a vigorous reaction were added in small quantities over a period of eight hours. When a clear solution had been obtained it was filtered through
glass wool and poured into five litres of cold water when the m-thiolbenzoic acid was precipitated. It was filtered off and after recrystallisation from aqueous ethyl alcohol had m.p. 146°.

It was found that when m-chlorosulphonylbenzoic acid was reduced in this manner a hard white solid was occasionally precipitated during the course of the reaction. It was isolated and identified as m-dithiobenzoic acid (Smiles and Stewart, loc.cit.). Since it could be reduced in acetic acid solution by the addition of zinc, its precipitation during the course of these reductions suggests that it forms an intermediate stage in the reduction of m-chlorosulphonylbenzoic acid under the experimental conditions employed, rather than that it arises through atmospheric oxidation of the thiol acid.

m-Methylthiolbenzoic Acid.

Dimethyl sulphate (2 mols.) was added with frequent shaking to a solution of m-thiolbenzoic acid (1mol.) in dilute aqueous caustic soda solution. After allowing the solution to stand for two hours the liquid was filtered and the m-methylthiolbenzoic acid precipitated by the addition of concentrated hydrochloric acid. It was washed with cold water and when recrystallised from aqueous ethyl alcohol was obtained as shining leaflets, m.p. 125-126°. Yield 60% of theoretical.
dl-m-Carboxyphenylmethylsulphoxide.

It was found that the oxidation of m-methylthiolbenzoic acid to the corresponding sulphoxide by means of 30% hydrogen peroxide needed very careful control to avoid the formation of the sulphone. This is contrary to the statement of Hinsberg that the use of hydrogen peroxide for such oxidations ensures that only sulphoxides will be produced, but it is in agreement with Gazdar and Smiles (J., 1908, 28, 1833) who pointed out that unless the reaction mixture was maintained at a low temperature sulphones were also produced.

The procedure which was found to be the most convenient and to form the least quantity of sulphone was as follows:

m-Methylthiolbenzoic acid (30 g.) was dissolved in a solution of anhydrous potassium carbonate (37 g.) in water (250 c.c.) and warmed to 40°. 40 G. of 30% hydrogen peroxide (Merck's 'Perhydrol' - 100 vols.) were then added very slowly with continuous stirring. The temperature was observed carefully whilst the excess oxygen was liberated and it was not allowed to rise above 70°. The addition of the hydrogen peroxide required about ten minutes. The solution was cooled, filtered and the sulphoxide precipitated by making just acid with a little concentrated hydrochloric acid. The precipitate, after filtration, was washed with water and dried. It was an almost colourless powder, m.p. 166°.
The small quantity of sulphone which was present was removed from the sulphoxide by taking advantage of the well-known basic properties of the sulphoxide grouping and also the insolubility of \textit{m}-carboxyphenylmethylsulphone in cold aqueous solution of mineral acids.

12 g of impure \textit{m}-carboxyphenylmethylsulphoxide, prepared as described above, m.p. 166°, were dissolved in warm concentrated hydrochloric acid (50 c.c.). The solution thus obtained was filtered, cooled in ice and allowed to stand for three hours. The \textit{m}-carboxyphenylmethylsulphone slowly crystallised from the acid solution which was then filtered and diluted with water (100 c.c.). The \textit{dl}-\textit{m}-carboxyphenylmethylsulphoxide which immediately crystallised from this diluted solution was washed with water, dried and then had m.p. 170-172°.

\textit{dl}-\textit{m}-Carboxyphenylmethylsulphoxide was found to be sparingly soluble in hot water, easily soluble in hot alcohol or acetone, but only slightly soluble in warm benzene or cold chloroform. It crystallised from hot water or alcohol in the form of small colourless prisms, m.p. 171-172°. It did not give a blue-green colouration with concentrated sulphuric acid which Smiles and Gazdar (J., 1908, 22, 1833) showed to be a typical reaction of many aromatic sulphoxides.

0.3183 of \textit{dl}-\textit{m}-carboxyphenylsulphoxide neutralised 0.0685 g of sodium hydroxide. Theory requires 0.0691.

(Found: C, 51.9; H, 4.5. \textit{C}_8\textit{H}_6\textit{SO}_3 requires C, 52.2; H, 4.35%).
The Resolution of dl-m-Carboxyphenylmethylsulphoxide.

dl-m-Carboxyphenylmethylsulphoxide (97 g.) was dissolved in acetone (3,000 c.c.), and l-brucine (207 g.) was then added and the mixture heated under reflux until the brucine had dissolved. The solution was filtered and cooled, when a crop of small hard crystals of the brucine salt was obtained, m.p. 115° and with rotatory power \( \alpha J_{5461} = -13.2° \) in chloroform solution (c=3.96, l=2.0). The salt was redissolved in acetone (6,000 c.c.) from which 2,500 c.c. were subsequently removed by evaporation. The next crop obtained on cooling had m.p. 121-122° and \( \alpha J_{5461} = -14° \) under the same conditions.

It was then found that one recrystallisation of the salt from methyl alcohol produced a far greater change in its rotatory power. The whole of the salt was therefore recovered from the acetone mother liquors and, together with the last crop, recrystallised from methyl alcohol (500 c.c.). In this manner from 275 g. of the salt 130 g. were obtained with m.p. 128-130° and \( \alpha J_{5461} = +8.5° \) in chloroform solution (c=3.96, l=2.0). This crop was systematically recrystallised and after fourteen recrystallisations was unchanged in rotatory power by further recrystallisation either from methyl alcohol or from water. The salt then had m.p. 136-137° and \( \alpha J_{5461} = +40.3° \) in chloroform solution (c=3.96, l=2.0).
The Recovery of d-m-Carboxyphenylmethylsulphoxide from its
1-Brucine Salt.

Before decomposing the main crop attempts were made to
find a method of recovering the sulphoxide in good yield from
fractions of the partially active salt. A solution of the
brucine salt in water was made alkaline to phenolphthalein
with slight excess of caustic soda solution and after standing
overnight the precipitated brucine was filtered off and washed
from adhering liquor with a little water. The solution of the
sodium salt thus obtained was evaporated to a small bulk and
after the addition of concentrated hydrochloric acid until the
solution was just acid to carmo red the sulphoxide began to
crystallise from the solution. It was filtered off, washed with
cold water and dried, but only a very poor yield (about 25% of the
theoretical quantity) was obtained. Previous extraction of the
brucine by means of chloroform before acidification of the
alkaline solution did not increase the yield of sulphoxide.
Precipitation of the brucine as brucine oxalate by the addition
of sodium oxalate to an aqueous solution of the salt and
acidification of the aqueous filtrate obtained from the mixture
was also unsatisfactory.
The yield of sulphoxide recovered by these methods was never more
then 50% and often did not exceed 25% of the theoretical quantity,
calculated from the weight of anhydrous salt taken, although
every possible effort was made to recover the sulphoxide from the
filtrates.
filtrates. The purity of the brucine salt was established by analysis:

(Found: C, 64.2; H, 6.2; C_{31}H_{34}N_{2}SO_{7} requires C, 64.3; H, 5.9%).

The next step consisted in titrating the aqueous solution with standard sodium hydroxide solution using sodium hydroxide as an indicator. Two methods were used, the first being direct titration and the second back titration after the addition of a known amount of standard hydrochloric acid solution sufficient to decompose the salt and liberate the free sulphoxide. The results of both these titrations appeared to indicate that the salt contained only about 20% of sulphoxide by weight, instead of 31% calculated on the hypothesis that one molecule of the sulphoxide is combined with one molecule of brucine. It was fortunately discovered that if the brucine salt was titrated in 50% aqueous ethyl alcohol solution instead of in water it reacted as though it contained the expected amount of the sulphoxide - namely 31%. It may be that the sulphoxide when optically active and presumably in the monomolecular condition would be capable of undergoing internal neutralisation (being then an amphoteric substance) and might not under the experimental conditions employed require as much alkali for complete neutralisation in aqueous solution as it would require when in the racemic condition. This explanation which can account for the experimental facts has been dealt with in more detail on page 41.
In the light of the foregoing experiment the following procedure for the decomposition of the l-brucine salt of d-m-carboxyphenylmethylsulphoxide was adopted and a yield of 75% was obtained. The l-brucine salt (25 g.) was dissolved in 96% ethyl alcohol (100 c.c.) and sufficient water (55 c.c.) was added to make the final content of alcohol 50% after the addition of the normal solution of potassium hydroxide. A few drops of phenolphthalein were added and the caustic potash solution was run in slowly from a burette until a permanent pink colouration was produced. The solution was allowed to stand for one hour and was then extracted repeatedly with chloroform. After seven extractions the chloroform was found to be free from brucine. The solution of the potassium salt of the sulphoxide was evaporated slowly on the water bath to about 30 c.c. when concentrated hydrochloric acid was added very carefully with continuous stirring until the solution was just acid to congo-red paper. A heavy precipitate of d-m-carboxyphenylmethylsulphoxide began to appear before all the acid had been added. A portion of this sulphoxide was found to be very much more soluble in chloroform than the inactive material and hence chloroform (about 500 c.c.) was added and the mixture well shaken. The small aqueous layer was removed in a separatory funnel and the chloroform solution dried with a little anhydrous sodium sulphate. The sulphoxide was completely precipitated from this solution by the addition of three times its volume of petroleum ether. d-m-Carboxyphenylmethyl-
The sulphone (6 g.) was then obtained in the form of fine white crystals, m.p. 130-131° and with rotatory power $\alpha 25°$. This amount represents a yield of 78%.

The lowering of the melting point of the compound by 40° and the greatly increased solubility in chloroform were the first indications of the existence of the inactive modification as a well defined racemic compound of the two enantiomorphic forms.

In the preliminary experiments on the decomposition of the L-brucine salt a yield of 25% of the sulphone with rotatory power $\alpha 23°$ in chloroform solution was obtained from a specimen of the L-brucine salt with $\alpha 24°$. Since the L-brucine salt of the DL-sulphone has $\alpha -14°$ and the salt of the sulphone has $\alpha +40.3°$ it would be expected that the rotatory power of the sulphone obtained from the salt with $\alpha +24°$ would be about $\alpha +90°$. Since experiment has shown that it is only about $+25°$ it is evident that the remaining 75% which was not recovered must have been in a very much higher state of optical purity. This can be understood to some extent when the increased solubility of the dextrorotatory modification is taken into account.
An Investigation of the Optical Purity of \(\text{d-\text{m-}}\)carboxyphenylmethylnsulphoxide with Specific Rotatory Power \(\left[\alpha\right]_{D}^{25} +125^\circ\) in Methyl Alcoholic Solution.

Subsequent reprecipitation by petroleum ether of the \(\text{d-\text{m-}}\)carboxyphenylmethylnsulphoxide with a specific rotatory power of \(\left[\alpha\right]_{D}^{25} +125^\circ\) from its solution in chloroform appeared to indicate that it was not optically pure since the portion precipitated had \(\left[\alpha\right]_{D}^{25} +129^\circ\) whilst the substance which remained in solution and was recovered by evaporation of the mixed solvents had \(\left[\alpha\right]_{D}^{25} +103^\circ\). In order to confirm the inference that the substance with specific rotatory power \(\left[\alpha\right]_{D}^{25} +125^\circ\) was not optically pure it was combined in acetone solution with the theoretical amount of \(\text{l-menthylamine}\)
\(\left[\alpha\right]_{D}^{19} +66^\circ\). The salt obtained, 6 g., m.p. 168-169°, and with \(\left[\alpha\right]_{D}^{5461} +69^\circ\) in ethyl alcoholic solution, \((\alpha=2.50, \lambda=1.0)\), was recrystallised from hot acetone (in which it is sparingly soluble) and after three recrystallisations there was no further increase in rotatory power. The \(\text{l-menthylamine}\) salt then weighed 5 g. and had m.p. 171° and \(\left[\alpha\right]_{D}^{5461} +69^\circ\) \((\alpha=2.51, \lambda=1.0)\).

This salt was decomposed by the same method as that used in the case of the \(\text{l-brucine}\) salt, except that ether was used instead of chloroform for the extraction of the liberated base. 1.75 G of \(\text{d-\text{m-}}\)carboxyphenylmethylnsulphoxide were recovered with \(\left[\alpha\right]_{D}^{25} +137^\circ\) and hence the \(\text{l-brucine}\) salt \(\left[\alpha\right]_{D}^{5461} +40.5^\circ\) was not optically pure.

(Found: C, 52.15; H, 4.4. \(\text{C}_8\text{H}_{18}\text{SO}_3\) requires C, 52.17; H, 4.35%).
Attempts were made to combine dl-m-carboxyphenylmethylsulphoxide and the laevorotatory sulphone with $\left[\alpha\right]_{5461}^{\circ} -15^\circ$ (obtained from the filtrates from the recrystallisation of the brucine salt) with other alkaloids such as morphine, strychnine and cinchonine, but it was not found possible to obtain crystalline salts. It was therefore decided to take advantage of the great difference in the solubilities of the dl- and the d- or l- forms. Accordingly, the l-brucine salt (64 g.), contained in the filtrate from the first recrystallisation of a second batch of material which had been prepared, was decomposed in the manner already described. After the precipitation of the sulphoxide by hydrochloric acid, a quantity of chloroform, (about 250 c.c.) insufficient to dissolve completely the liberated sulphoxide, was added and the mixture well shaken. The chloroform layer was then separated and the undissolved solid material removed from the aqueous layer by filtration. The residual solid weighed 5.5 g. and had m.p. 170-171° and $\left[\alpha\right]_{5461}^{\circ} -8^\circ$ in methyl alcoholic solution. The substance which was precipitated from the chloroform solution by the addition of petroleum ether weighed 10 g. and had m.p. 133° and $\left[\alpha\right]_{25}^{5461} -122^\circ$. By this method the laevorotatory isomeride had been obtained in a condition approaching optical purity in only two operations. A small portion (2 g.) of 1-+ dl- m-carboxyphenylmethylsulphoxide with $\left[\alpha\right]_{5461}^{\circ}$.
with $[\alpha]_{5461}^\circ = -122^\circ$ was treated with insufficient chloroform to dissolve it completely (10 c.c.) and the undissolved portion was removed and examined. The portion which was dissolved by the chloroform was also recovered by the addition of petroleum ether. It was found that both these fractions had remained unchanged in rotatory power, indicating that solution in chloroform or precipitation by petroleum ether do not cause the formation of the racemate from the mixture of the two optical isomericides. Nevertheless, the racemate is formed when the substance is dissolved in alkali and reprecipitated by the addition of acid, and by this means the optically pure laevorotatory isomericide was quite easily obtained.

The sulphoxide with specific rotatory power $[\alpha]_{5461}^\circ = -122^\circ$ in methyl alcoholic solution was dissolved in dilute caustic soda, precipitated by acid and extracted with a deficiency of chloroform; the chloroform solution yielded a product with enhanced rotatory power. After repeating this operation twice the rotatory power of the sulphoxide was not further increased by repetition of the process. 1.6 G. of 1-<em>m</em>-carboxyphenylmethylsulphoxide were thus obtained with m.p. 133° and rotatory power $[\alpha]_{5461}^{25^\circ} = -135^\circ$ in methyl alcoholic solution, which is equal to that of the dextrorotatory isomericide within the limits of experimental error.

(Found: C, 52.0; H, 4.4 . C$_9$H$_8$SO$_3$ requires C, 52.17; H, 4.35%).
The Oxidation of d-m-Carboxyphenylmethylsulphoxide to m-Carboxyphenylmethylsulphone.

d-m-Carboxyphenylmethylsulphoxide (0.5 g.) m.p. 133° and specific rotatory power $[\alpha]_25^0 = +137^0$ (c=2.5, l=1.0) in methyl alcohol, was dissolved in 19 c.c. of glacial acetic acid together with 6 c.c. of water and heated to 60° for one hour with the addition of 0.35 g. of finely powdered potassium permanganate. After dilution with 150 c.c. of water sulphur dioxide was passed through the solution until all the manganese dioxide was dissolved and the resulting liquid was colourless. On cooling, a precipitate of m-carboxyphenylmethylsulphone was obtained with m.p. 229-231° alone, and when mixed with an authentic specimen obtained by the oxidation of dl-m-carboxy-phenylmethylsulphoxide of m.p. 171°.

0.201 G. of m-carboxyphenylmethylsulphone prepared from the optically active material when made up to 10 c.c. with N/10 caustic potash solution and observed in a 100 mm. tube in the polarimeter was found to be inactive to light of $\lambda$, 4359 and 5461.
Recombination of the d- and l- forms of m-Carboxyphenyl- 
methyisulphoxide.

A further proof of the chemical relationship existing 
between the active forms and the inactive racemic form of 
m-carboxyphenylmethylsulphoxide was their easy recombination 
to form the less soluble racemate of higher melting point. 
0.1 G. of each of the two active substances, m.p. 133° was 
dissolved separately in the minimum quantity (1.3 c.c.) of 
cold chloroform. The two solutions obtained were then mixed 
and shaken, when a bulky crystalline precipitate was 
immediately formed, which, after filtration and washing with 
1 c.c. of cold chloroform, weighed 0.17 g. (85% of the original) 
and had m.p. 170-171°. This melting point was not depressed 
on mixing with the original substance, m.p. 170-171°. 
Furthermore, the product was devoid of optical activity.
(b) dl-4-Amino-4'-methyldiphenylsulphoxide.

dl-4-Amino-4'-methyldiphenylsulphoxide has not previously been described although there is a reference to its production during the manufacture of German dyes:

D.R.P. 270942
269799

Hinsberg (Ber., 1903, 36, 107) describes the preparation of the analogous phenyl compound, 4-aminodiphenylsulphoxide *** by heating together benzene sulphinic acid and an excess of aniline at 100° for 12 hours. He obtained a product which crystallised from water in the form of colourless needles, m.p. 152°.

By a precisely similar method 4-amino-4'-methyldiphenylsulphoxide has now been prepared.

*** That during such interactions the R.SO- group enters the aniline nucleus in the p-position was proved by Hinsberg (loc. cit.) who showed that the aminodiphenylsulphoxide produced from aniline and benzenesulphinic acid gave an aminodiphenylsulphide, m.p.95° (acetyl derivative, m.p.148°), on reduction. Kehrmann and Bauer (Ber., 1896, 29, 2334) obtained p-aminodiphenylsulphide, m.p.93° (acetyl derivative, m.p.143°) by the following series of reactions which leave no doubt as to the correct orientation of this sulphide: 4-4'-dinitrodiphenylsulphide, obtained by the interaction of sodium sulphide and p-chloronitrobenzene, gave, on reduction with ammonium sulphide, 4-nitro-4'-aminodiphenylsulphide; elimination of the amino group from this sulphide and reduction of the p-nitrodiphenylsulphide obtained gave the required p-aminodiphenylsulphide.
p-Toluenesulphinic acid was prepared from p-toluene-
sulphonyl chloride by the method of Blomstrand (Ber., 1870, 3, 965) using a solution of sodium sulphite. Carefully dried
p-toluenesulphinic acid was heated at 110-115° for thirty hours
with four times its weight of redistilled aniline. After
removal of the excess of aniline by distillation in a current
of steam the residue, the residue which consisted of a heavy red
oil, solidified to a crystalline solid on cooling. This heavy
red solid was found to be only partially soluble in dilute
hydrochloric acid and accordingly a separation of its components
was effected by dissolving it in ether and extracting the
ethereal solution with dilute hydrochloric acid until the
extracts yielded no further precipitate on neutralisation with
sodium carbonate solution. The substance obtained by
precipitation with sodium carbonate solution was of a slightly
pink colour, but most of the colour was removed by recrystallisation
from an alcoholic solution which had been boiled several times
with 'Norit'. The substance proved on analysis to be 4-amino-4'-
methyldiphenylsulphoxide.

(Found: C, 67.6; H, 5.98; N, 6.00. C H N S O requires C, 67.5;
H, 5.63; N, 6.06%).

It consisted of faintly pink needles, m.p. 169-170° and was
obtained in 27% yield. It was found to be only slightly
soluble in hot water, easily soluble in hot ethyl alcohol or
chloroform and sparingly soluble in benzene.
The Resolution of dl-4-Amino-4'-methylenebisphenylsulphoxide.

The resolution of this amine into its optically active isomeres was accomplished by the recrystallisation of the salts which it forms with d- and l-camphorsulphonic acids.

Attempts were made to resolve the substance by recrystallisation of the d-camphorsulphonate from such solvents as acetone, ethyl alcohol, ethyl acetate and amyl alcohol, but although resolution did occur to some extent, the results were by no means as satisfactory as when water was used.

dl-4-Amino-4'-methylenebisphenylsulphoxide (55 g.) was dissolved in a hot solution of d-camphorsulphonic acid (60 g.) in 100 c.c. of water. The theoretical quantity of acid required is 55 g. but the slight excess which was used was necessary to prevent hydrolysis of the salt which occurs very readily on further dilution of the aqueous solution.

The salt crystallised on cooling in the form of rosettes of fine needles, m.p. 155-162°, which were recrystallised from 100 c.c. of water containing 2 g. of d-camphorsulphonic acid. The filtrates from the first two recrystallisations of the crop were decomposed by the addition of dilute ammonia solution and yielded 26 g. of a laevorotatory sulphoxide with \( \alpha = 1.0, \beta = 2.0 \).
1-4-Amino-4'-methyldiphenylsulphoxide.

The sulphoxide with $[\alpha]_{5461}^{25} = -33^\circ$ (26 g.) was recrystallised from ethyl alcohol and then weighed 20 g. and had m.p. 162-168° and $[\alpha]_{5461}^{25} = -24^\circ$ in chloroform solution ($c=1.32$, $l=2.0$). By dilution of the concentrated mother liquor with water the more soluble laevorotatory sulphoxide was precipitated as a bulky crop of fine hair-like needles (6 g.) with $[\alpha]_{5461}^{25} = 81.6^\circ$ in chloroform solution ($c=1.0$, $l=2.0$). This laevorotatory sulphoxide was dissolved in a hot aqueous solution of 1-camphorsulphonic acid ** (6.5 g.) in water (25 o.c.), and, on cooling, a crop of crystals of the 1-camphorsulphonate of the optically impure 1-sulphoxide was deposited as rosettes of fine needles. The sulphoxide, which was recovered by the addition of a large volume of water to the filtrate had $[\alpha]_{5461}^{25} = -10.7^\circ$ in chloroform solution, showing that the resolution was proceeding rapidly. After six recrystallisations from water containing small quantities of 1-camphorsulphonic acid the salt was considered to be optically pure since the rotatory power of the sulphoxide recovered from the mother liquor was equal to that of the sulphoxide recovered from the crop.

Thus isolated, 1-4-amino-4'-methyldiphenylsulphoxide - 1-camphorsulphonate had m.p. 133-134° and $[\alpha]_{5461}^{25} = -16.2^\circ$ in ethyl alcoholic solution ($c=3.75$, $l=2.0$).
1-4-Amino-4'-methyl-diphenyl-sulphoxide, obtained by the decomposition of this salt, crystallised from aqueous ethyl alcohol in long slender hair-like needles, m.p. 151°. It had [α]_D^{25} +38.6° in chloroform and −122° in ethyl alcoholic solution.

(Found: C, 67.2; H, 5.86; S, 14.3. \( C_{13}H_{13}NSO \) requires C, 67.5; H, 5.83; S, 14.9%).
**d-4-Amino-4'-methyldiphenylsulphoxide.**

The salt formed by the optically impure d-sulphoxide with d-camphorsulphonic acid as described on page 90 was recrystallised fifteen times from dilute aqueous solutions of d-camphorsulphonic acid. On decomposition of a portion of the final crop a dextrorotatory sulphoxide was obtained with $[\alpha]_{D}^{25°} 5461 + 60°$ in chloroform solution ($c=1.25$), a value identical with the rotatory power of the dextrorotatory sulphoxide obtained from the final mother liquor. Since five additional recrystallisations of the salt produced no further resolution, it was decomposed and the sulphoxide obtained recrystallised twice from ethyl alcohol. d-4-Amino-4'-methyldiphenylsulphoxide was obtained in this way with m.p. 151° and with $[\alpha]_{D}^{25°} 5461 + 89.9°$ in chloroform solution ($c=1.28, l=2.0$) and with $[\alpha]_{D}^{25°} 5461 + 123°$ in ethyl alcoholic solution ($c=1.21, l=2.0$) values equal in magnitude within the limits of experimental error, to those possessed by the l-sulphoxide obtained, as described, from l-4-amino-4'-methyldiphenylsulphoxide l-camphorsulphonate.

(Found: C, 67.6; H, 5.80; S, 13.8. $C_{13}H_{13}NSO$ requires C, 67.5; H, 5.63; S, 13.9%).

---

This result was quite unexpected since the resolution of the optically impure l-4-amino-4'-methyldiphenylsulphoxide l-camphorsulphonate prepared from a laevorotatory sulphoxide with $[\alpha]_{D}^{5461} -42°$ proceeded quite normally.
d-4-Amino-4'-methyldiphenylsulphoxide d-camphorsulphonate.

This salt was prepared from the d-4-amino-4'-methyldiphenylsulphoxide and had m.p. 133-134° and $[\alpha]_{D}^{5461} +17.2^\circ$ in ethyl alcoholic solution ($c=3.75, l=2.0$), which agrees closely with the values obtained for the rotatory power of the laevorotatory isomeride.

The Recombination of d- and l-4-Amino-4'-methyldiphenylsulphoxide

A solution of the d-sulphoxide, m.p. 151° (0.2 g.) in warm ethyl alcoholl (1.5 c.c.) was added to a similar solution of the l-sulphoxide m.p. 151°. The clusters of hairy needles which immediately began to separate from the mixed solutions weighed 0.33 g. (80%) and had m.p. 189-170° alone, and when mixed with the dl-sulphoxide.
Preparation of dl-4-Acetamino-4'-methyldiphenylsulphoxide.

This compound crystallised from a solution of dl-4-amino-4'-methyldiphenylsulphoxide (7 g.) in acetic anhydride (7 c.c.). The sulphoxide was dissolved and the solution heated to 80° for five minutes. The mixture was then cooled and the product precipitated by the addition of water. It was well washed with water and recrystallised from aqueous ethyl alcohol, when 7.6 g. of feathery needles, m.p. 183-184°, were produced.

(Found: C, 65.3; H, 5.6. \(C_{16}H_{16}O_2NS\) requires C, 65.9; H, 5.5%).

Preparation of 1-4-Acetamino-4'-methyldiphenylsulphoxide.

This was prepared in the same way as the compound described above and had m.p. 173-174° after recrystallisation from aqueous alcohol. It was noticed that the solubility of the product was much greater than the solubility of the acetyl derivative prepared from the dl-sulphoxide.

0.2490 G. were made up to 20 c.c. with ethyl alcohol and the rotatory power of the solution obtained in a 200 mm. tube at 25°.

<table>
<thead>
<tr>
<th>(\lambda)</th>
<th>6708</th>
<th>5893</th>
<th>5461</th>
<th>4359</th>
<th>6708</th>
<th>5893</th>
<th>5461</th>
<th>4359</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\Delta^\circ)</td>
<td>-1.07°</td>
<td>-1.34°</td>
<td>-1.68°</td>
<td>-3.93°</td>
<td>(\Delta^\circ)</td>
<td>-43.0°</td>
<td>-53.8°</td>
<td>-66.2°</td>
</tr>
</tbody>
</table>

\(l=2.0\)
Preparation of d-4-Acetamino-4'-methyldiphenylsulphoxide.

Although this substance (prepared in a similar way from d-4-amino-4'-methyldiphenylsulphoxide) was recrystallised repeatedly from ethyl alcohol and aqueous acetic acid its specific rotatory power remained unchanged at \([\alpha]_25^\circ +42^\circ\), \([\alpha]_5893^\circ +52.4^\circ\), \([\alpha]_5461^\circ +66.4^\circ\) \((c=1.25, l=2.0, \text{ in ethyl alcoholic solution})\), values in close agreement with those obtained for the laevorotatory isomeride.
4-Acetamino-4'-methyl diphenyl sulphone.

Finely ground potassium permanganate (1.0 g.) was added to a solution of dl-4-amino-4'-methyl diphenyl sulphone (1.36 g.) in warm acetic acid (50°C). The mixture was gently heated and agitated for half an hour when the solution was diluted with water and decolourised by the passage of sulphur dioxide gas. The sulphone remained as a crystalline precipitate. After allowing the mixture to stand for one hour the precipitate was removed by filtration and recrystallised from aqueous ethyl alcohol. It was obtained as hard shining leaflets, m.p. 194°.

(Found: C, 62.2; H, 5.2. \(\text{C}_{15}\text{H}_{15}\text{O}_{3}\text{NS}\) requires C, 62.3; H, 5.2%).

The Oxidation of d-4-Acetamino-4'-methyl diphenyl sulphoxide to 4-Acetamino-4'-methyl diphenyl sulphone.

d-4-Acetamino-4'-methyl diphenyl sulphoxide (1 g.) was oxidised as described above and the sulphone obtained had m.p. 192° alone, and when mixed with the substance obtained by the oxidation of the inactive material. 0.5 g. made up to 20 c.c. with pyridine and observed in a 200 mm. tube was optically inactive to light of \(\lambda\), 5461 and 4359.
PART III
EXPERIMENTAL

THE OPTICAL PROPERTIES OF d-\textbf{\lowercase{OCTYLPHENYL}}CARBA\textbf{\lowercase{MATE}}.

Ethylphenylcarbamate.

The ethylphenylcarbamate used in these investigations was prepared by the distillation at low pressures of a commercial sample (phenylurethane). The substance distilled as a colourless liquid with boiling point 110°/0.25 mm, which solidified to form colourless crystals, m.p. 51-52°. When observed in a 100 mm. tube at 65° in the polarimeter the product was inactive to light of \( \lambda \), 5461 and 5893.

d-\textbf{\lowercase{OCTYLPHENYL}}CARBA\textbf{\lowercase{MATE}}.

Mention was made by Block (Bull. Soc. Chim., 31, 49), of the \textit{d} form of this compound which he obtained as a colourless liquid by the interaction of phenylisocyanate and \textbf{\lowercase{\textit{OCTYL}}}octanol. Brooks and Humphrey (J. Amer. Chem. Soc., 1918, 40, 839) claim to have prepare octylphenylcarbamate (octylphenylurethane) by the interaction of phenylisocyanate and a substance which they identified as \textbf{\lowercase{\textit{OCTYL}}}octanol by means of its odour. They obtained a crystalline product which, on recrystallisation from alcohol had m.p. 235°. No analytical
data were quoted to justify this conclusion. There is no doubt that the substance obtained by these authors was actually carbanilide (diphenylurea) m.p. 235-238°, which was produced by the decomposition of the phenylisocyanate. Small quantities of carbanilide were similarly obtained during the course of the present work. The method of Block, which is a general method for the preparation of phenylurethanes, was employed to prepare d-β-octylphenylcarbamate. The reaction may be represented as:

\[ d-C_{6}H_{17}OH + C_{6}H_{5}N:CO \rightarrow d-C_{6}H_{5}NH COOC_{6}H_{17}. \]

d-β-octanol (22.5 g.) was mixed with phenylisocyanate (21 g.) and the mixture, which rapidly became warm, was heated for two hours on a water bath. After standing for twenty hours the product was distilled in a very high vacuum. About 1 g. of low-boiling material was obtained and the remainder, d-β-octylphenylcarbamate (40.2 g.) was collected at 129-135°/0.1 mm. - the glycerine bath in which the flask was heated was maintained at 145-149°.

d-β-octylphenylcarbamate was a clear colourless, almost odourless, viscous liquid which was easily obtained solid by cooling in a freezing mixture. It then had m.p. 28-29° and \([\alpha]_{D}^{25°} 25° 5461 + 2.12°, [\alpha]_{D}^{25°} 25° 252° 5893 + 1.90°.\]

The refractive index was \( n_{5893} 1.5083. \)

(Found; N, 6.8. \( C_{6}H_{19}O_{2}N \) requires N, 6.9%)

The substance prepared in this way was immediately used for the
fractional distillation experiment described on page 104.

The Interaction of Ethylphenylcarbamate (2 mols.) with d-β-Octanol (1 mol.).

Ethylphenylcarbamate (2 mols., 25 g.) was heated with d-β-Octanol (1 mol., 10 g.) at 40 mm. for 60 hours at 100°.

On subsequent distillation at low pressures (under 0.1 mm.) it was found that this temperature was not high enough to cause any appreciable displacement of the ethyl alcohol and the whole of the material was recovered unchanged. Heating in an oil bath at 160° for fifteen hours was also unsuccessful. The reaction was eventually carried to completion by heating the mixture at a temperature slightly above 175° at which point gentle refluxing of the contents of the reaction flask occurred. The mixture was heated for 24 hours and then, after cooling, and subsequent warming to 100° in a vacuum of 15 mm. until all frothing had ceased, it was distilled at low pressure, using two mercury jet pumps backed by a Pleuss pump.

Under the pressure employed it was almost impossible to collect the traces of d-β-Octanol which remained. Fractions which distilled over below 80° were neglected, but were always quite small in amount. The temperature of the heating vessel was maintained at about 15° above the temperature of distillation and the rate of distillation was made as slow as possible. The
connecting tube to the receiver was occasionally warmed to prevent solidification of the ethylphenylcarbamate, but very little difficulty was experienced from this in view of the wide bore of the tubes required for low pressure distillations. The reaction can be represented as:

\[ 2 \text{C}_6\text{H}_5\text{NH} \cdot \text{CO} \cdot \text{OC}_2\text{H}_5 + \text{d-C}_6\text{H}_{17}\text{OH} \rightarrow \text{C}_6\text{H}_5\text{NH} \cdot \text{CO} \cdot \text{OC}_2\text{H}_5 + \text{C}_2\text{H}_5\text{OH} + \text{d-C}_6\text{H}_{17}\text{NH} \cdot \text{CO} \cdot \text{OC}_2\text{H}_5 \]

Ethylphenylcarbamate distilled over in the fraction which had b.p. 80-100° and above the higher temperature the distillate consisted chiefly of d-\(\beta\)-octylphenylcarbamate. A small quantity of a solid residue was always left in the distillation flask: this was removed and recrystallised from ethyl alcohol and obtained in the form of lustrous plates, m.p. 235°. This is the melting point of carbanilide (diphenylurea) and the melting point of the crystals was not depressed by mixing them with an authentic specimen of carbanilide. The carbanilide was probably formed by slight decomposition of the urethane at the temperature of the reaction.

In order to obtain the ethylphenylcarbamate entirely free from d-\(\beta\)-octylphenylcarbamate, the higher boiling constituent, it was found necessary to collect it over a much narrower range of temperature in the second distillation; it was collected over a range of three degrees: 87-90°. The purity of the product was indicated by the ease with which it solidified on cooling and by the firmness of the resulting
crystalline mass. Fractions which contained only a small amount of d-\( \beta \) -octylphenylcarbamate remained liquid at room temperature for nearly an hour, and when solid possessed no sharp melting point, becoming pasty when warmed. The melting point of pure ethylphenylcarbamate is 51-52\(^\circ\). In the first experiment the ethylphenylcarbamate recovered by distillation was found to be optically inactive in 5% solution in benzene. Since any optical activity which it might show would probably be of a very small order of magnitude subsequent observations were made on the homogeneous substance at 65\(^\circ\).

In the next experiment ethylphenylcarbamate (17.5 g.) and d-\( \beta \) -octanol (7 g.) were heated and distilled as before, and a fraction (9 g.) with b.p. 80-100\(^\circ\) was collected. After refractionation the central fraction (6 g., b.p. 86-92) was collected and examined. This fraction solidified with difficulty and, when solid, had no definite melting point. It was found to be optically active and laevorotatory. It had

\[
[\alpha]_{\text{D}}^{65\degree} = -0.25^\circ, \quad [\alpha]_{\text{D}}^{5461} = -0.14^\circ \quad (l=0.5),
\]

The optical activity of this product could arise from three possible causes:–

1. The presence of d-\( \beta \) -octanol.
2. The presence of d-\( \beta \) -octylphenylcarbamate.
3. The presence of an optically active form of ethylphenylcarbamate.
Determinations were accordingly made of the rotatory power of dilute solutions of $d$-$\beta$-octanol and $d$-$\beta$-octylphenylcarbamate in ethylphenylcarbamate. The ethylphenylcarbamate used as the solvent was shown to be optically inactive and was purified by distillation as described on page 98.

The Rotatory Power of a Solution of $d$-$\beta$-Octanol in Ethylphenylcarbamate.

0.497 G. of $d$-$\beta$-octanol was made up to 4.952 g. with ethylphenylcarbamate and observed in a 50 mm. tube at 65°. It had $\lambda_{5461}^\circ +0.47^\circ$ and $\lambda_{4359}^\circ +0.68^\circ$.

The Rotatory Power of a Solution of $d$-$\beta$-Octylphenylcarbamate in Ethylphenylcarbamate.

0.195 G. of $d$-$\beta$-octylphenylcarbamate was made up to 5.118 g. with ethylphenylcarbamate; the solution was observed in a 50 mm. tube at 65°. It was found to be laevorotatory and had:

$\lambda_{4359}^\circ -0.36^\circ$, $\lambda_{5461}^\circ -0.19^\circ$, $\lambda_{5893}^\circ -0.09^\circ$, $\lambda_{6703}^\circ -0.04^\circ$.

This result indicated that the laevorotatory power observed in the ethylphenylcarbamate was probably due to the presence of a small quantity (about 3%) of $d$-$\beta$-octylphenylcarbamate.
By refractionation of the ethylphenylcarbamate at a much slower rate and collection of the distillate over a very much smaller range of temperature - 87-90° - it was obtained optically inactive and with the correct melting point.

From this result it was concluded that ethylphenylcarbamate was not capable of separation, by the methods employed, into optically active modifications. This conclusion was further tested by the preparation and fractionation of a large quantity of $d$-β-octylphenylcarbamate.

The Fractional Distillation of $d$-β-Octylphenylcarbamate.

$d$-β-Octylphenylcarbamate, obtained as described (page 99) was fractionally distilled from a flask with a long neck to assist fractionation, in an X-Ray vacuum. It was collected at the rate of three or four drops per minute, the complete distillation of 40 g. of material requiring ten hours. At this slow rate of distillation the boiling point recorded was reduced to 122-127°; the heating bath was maintained at 142-148°.

Six fractions were collected: the weight, refractive index and rotatory power are of each of these fractions are given in the table on the next page.
The rotatory power and refractive index of the samples were in every case determined as soon as possible after the removal of the sample from the receiver of the apparatus, so that the possible occurrence of any rapid change in these physical properties might be detected.

The fractions did not show any muta-rotation on standing for several weeks. On the following day following the distillation just described fraction I was redistilled under the same conditions and was separated into two fractions A and B. Fraction II was added to B and the distillation continued to obtain fraction C.
The rotatory powers and refractive indices of A and C were identical with those of the fractions previously obtained; hence it was concluded that \( d-\beta \)-octylphenylcarbamate cannot be separated into its possible isomeric forms by fractional distillation in the manner now described.