SOME FORENSIC ASPECTS OF CHEMICAL TESTS FOR ALCOHOL

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PREFACE

The results of work presented in this thesis were obtained, in the most part, from a series of experiments conducted in the Department of Pathology, University of Melbourne, over the period 1957-60. The nature of the experiments was such that they could not be carried out by one person and they were conducted by a group of workers under the direction of Dr. N. E. W. McCallum. Some of the results obtained have been published in the Medical Journal of Australia and in the Proceedings of the Royal Australian Chemical Institute under the following titles:—

1. Some Aspects of Alcohol in Body Fluids. Part I. Correlation between Blood Alcohol Concentration and Alcohol Consumption.

2. Some Aspects of Alcohol in Body Fluids. Part II. The Change in Blood Alcohol Concentration Following Alcohol Consumption.

3. The Determination of Blood Alcohol Concentration by Breath Analysis.
   R. C. Bayly, N. E. W. McCallum and W. L. K. Preston,

The work now reported is a portion of the results obtained from the experiments conducted by the above workers.

R. C. Bayly

5th December, 1960.
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1. INTRODUCTION.

The problem surrounding the ever increasing toll of death and injury arising from road accidents is one which is receiving increasing attention as the number of vehicles on the roads continues to rise. While it has not been possible to isolate any one factor as the sole or even primary cause of road accidents, several surveys have shown that in many accidents alcohol has been a contributory factor by affecting the faculties of the driver or pedestrian. It cannot be over-emphasized at the outset that caution must be used in accepting the results of many of these "surveys". All too frequently, causes are ascribed to certain factors by a single individual who has not actually observed the accident but has formed his opinion on what he has been told. The opinions then often tend to become authoritative pronouncements on the causes of road accidents.

In 1934, Heise investigated 119 automobile accidents which resulted in death or injury to 216 persons, and he found that in 74 accidents the persons involved had a blood alcohol concentration exceeding 0.02 per cent. He also noted that there was a trend towards higher blood alcohol concentrations as the severity of the accident increased. Heise does not state if his survey is based on his own investigation or on the results of hospital or police accident reports and so the accuracy of the survey cannot be assessed.

A similar pattern was observed by Holcomb in 1938 who
determined the concentration of alcohol in the blood of 270 drivers admitted to hospital following accidents involving personal injury. In 47 per cent of the cases the driver had been drinking and, in 25 per cent of these, the blood alcohol concentration was greater than 0.100 per cent. He also found that there were 33 times as many drivers with a concentration of 0.150 per cent in the group involved in personal injury accidents as in the general driving population. At concentrations of alcohol in the blood of approximately 0.05 per cent he found a similar percentage of drivers in both groups, and he concluded that a concentration of this magnitude (0.05 per cent) was not a significant factor in the cause of road accidents.

Other surveys by Smith and Popham (1951), Bowden, Wilson, and Turner (1958), and Haddon and Bradess (1959), confirmed the foregoing results. Smith and Popham based their conclusions on official accident reports, so care must be taken in interpreting these reports. Bowden and his colleagues determined the blood alcohol concentration on a group of drivers who had been killed in accidents and found that at least 25 per cent of them had a concentration exceeding 0.100 per cent. It must be noted, however, that the subjects examined were selected from cases where it was thought that alcohol was likely to be present, although the actual criteria on which this selection was based are not stated. Haddon and Bradess investigated 117 single-vehicle accidents which resulted in 87 deaths and they found that, in 69 per cent of those killed, the concentration of alcohol in the blood
at the time of death exceeded 0.05 per cent. Many of the drivers examined lived for periods up to four hours after the accident so that their concentration at the time of the accident was almost certainly higher than that found at post-mortem.

Since the pharmacological action of ethyl alcohol is that of a depressant of the functions of the central nervous system, it has therefore been concluded that alcohol is a contributory factor to road accidents in that it causes a deterioration of the normal functions of the driver or pedestrian.

The establishment of the proposition that alcohol was at least a contributory cause to road accidents has resulted in most countries in the enactment of legislation which makes it an offence for a person under the influence of alcohol to be in charge of a motor vehicle. Various types of legislation are in force in different countries and these will be discussed later (page 21).

The problems which arose in legislation to control this offence were to decide if there is some degree of alcoholic impairment at which all persons become unfit to control a motor vehicle, and if there is some method of determining when this stage is reached in such an individual.

Much work has been carried out to determine whether there is a significant correlation between the degree of impairment and the concentration of alcohol present in the blood. The methods used to determine the degree of impairment produced by alcohol include a
clinical examination by a medical practitioner, determination of the
effect on the sensory and motor functions of the brain, and tests
of psychological functions. From the results of these and similar
tests it has been concluded, as a generalization, that the degree
of impairment of all functions tested increases as the concentration
of alcohol in the blood increases. The experiments have also shown
that there is a difference in the effect of the same blood alcohol
concentration in different individuals. It is this individual
variation which let Gonzales (1954) to conclude that "Unfortunately,
no reliable test has been developed which will permit a quantitative
measure of the physiologic response of an individual in relation to
the alcohol level in the organs and fluids of the body".
2. FACTORS CAUSING INDIVIDUAL DIFFERENCES IN RESPONSE TO THE SAME BLOOD ALCOHOL CONCENTRATION

Different reasons have been advanced to explain why it is not possible to assess accurately the degree of impairment produced in an individual by a specific blood alcohol concentration. These reasons will be discussed briefly.

The reason most commonly advanced is that some persons exhibit a "tolerance" to the effect of alcohol. This question of tolerance has been the subject of much discussion in the literature but, as pointed out by McCallum (1954), no unanimity of opinion has been reached because the various authors have had different concepts of what constitutes "tolerance".

One of the most comprehensive reports on the subject of tolerance to alcohol was that of Goldberg (1943). He investigated the rates of absorption, distribution, and metabolism of alcohol, and the degree of mental impairment in a group of persons consisting of heavy or habituated drinkers, moderate drinkers, and abstainers. While he found no significant difference between the three groups in the above-mentioned rates, he observed that, at similar blood alcohol concentrations, the habituated group showed less reaction to alcohol as measured by the effect on the sensory, motor, and psychological functions. He concluded that the tissues in the habituated group had acquired a tolerance to the effect of alcohol. He also noted
that the habituated group had acquired the ability to compensate psychologically for the effect of alcohol on the tissues.

It must be noted that the differences observed by Goldberg occurred at relatively low blood alcohol concentrations - about 0.100 per cent. Other workers (Locmis and West, 1958; Coldwell and co-workers, 1958) have also observed that the heavy drinker is less affected in this range, but they found that the differences began to disappear as the blood alcohol concentration approached 0.150 per cent.

Another factor advanced in the explanation of the individual variation in behaviour produced by alcohol is the observation that a given concentration of alcohol in the blood produces more effect on the individual during the period of rising concentration than during the falling concentration period. This was first reported by Mellanby (1919) who found that dogs which were obviously intoxicated when the concentration of alcohol in the blood was rising, were almost normal at the same concentration when the value was decreasing. This is now referred to as the "Mellanby effect". Mellanby also noted that small increases in the concentration were sufficient to cause well-developed changes in the state of intoxication in the dogs and this may account for their apparent rapid recovery as the blood alcohol concentration decreased.

Similar observations in human subjects were made by Eggleton (1941), who found that the rate of recovery of functions
which had been impaired by alcohol was faster than the rate at which
the concentration of alcohol in the blood declined. No explanation
as to the possible cause of this effect was given.

Newman and Abramson (1941) reported that the effect of
a given concentration of alcohol depended not only on its absolute
value but also on the period during which it had been present in
the body. The subjects were kept for four hours at a concentration
of alcohol in the blood which was insufficient to produce intoxication;
the concentration was then increased to a level at which the subject
had previously exhibited intoxication. They found that the effect
on the subject was less on this occasion than when a similar
concentration was reached without any "holding" period. They
concluded that the alcohol had effected a change in the response
of the nervous system and that four hours "exposure" to alcohol was
a sufficient period for this acquired tolerance to be attained.
Since their results were obtained by testing only two subjects and
the degree of impairment produced was determined by the use of only
one test, the conclusions drawn by these authors should be viewed
with caution.

In 1943 Goldberg tested the sensory, motor, and
psychological reactions at different stages of the blood alcohol
curve of 17 normal individuals. He found that impairment of some of
the functions tested began at lower blood alcohol concentrations
than those at which the same symptoms disappeared, and he concluded
that these functions were more sensitive to a rising than a falling concentration of alcohol. Goldberg made no suggestion that the effect might be due to a rapidly acquired tolerance of the tissues.

Loomis and West (1958) reported results which opposed the theory of a rapidly acquired tolerance. They tested 10 subjects in a simulated driving apparatus at intervals of 1.5, 3, and 5 hours after the consumption of alcohol. The concentration of alcohol in the blood was kept at approximately the same level during the tests by the consumption of small amounts of alcohol each hour. They found that no improvement in the performance of the tests occurred in the last two hours, and it was concluded that no tolerance to alcohol had been acquired in the five hours exposure of the tissues to alcohol.

No definite conclusions have as yet been reached on this subject. Some of the early work was carried out on animals, the results of which may not be directly applicable to man. The type of test used to determine the degree of impairment may also be a difficulty. This second point was demonstrated by Goldberg (1943), who showed differences in the sensitivity of sensory, motor, and psychological functions to alcohol. It does seem that some variation in effect may be observed if the subject is tested at a given concentration at different stages of the blood alcohol curve, but it is not clear whether these variations are significant when the degree of impairment is judged on a series of tests.
A further factor suggested to explain the variations observed between degree of effect of alcohol and the concentration of alcohol in the blood is that the ratio between the blood and brain alcohol is not constant. The work in this field has necessarily been conducted on animals or is the result of analysis of samples obtained post-mortem.

Gettler and Tiber (1927) suggested that the concentration of alcohol in the brain was the true index of intoxication, and this led to considerable work being carried out to determine the ratio of brain alcohol to the blood and other body fluids.

As a result of a series of investigations on animals and cadavers, Gettler and his colleagues (1927, 1931, and 1944) stated that there was no regular relation between brain and blood alcohol concentrations. In assessing the results obtained by these workers two factors must be considered. First, the method of analysis used only recovered an average of 85 per cent of added ethanol and the indifferent accuracy of the method could be an explanation of some of the wide differences in blood/brain ratio reported. Secondly, some of the variations observed may also be attributed to the circumstance that examination of some animals took place before equilibrium between the blood and brain could have occurred while, in the examinations on cadavers, it was not possible to determine what stage of absorption the subjects had reached immediately before death.
Harger, Hulpieu, and Lamb (1937) reported that the average ratio between the concentrations of alcohol in the blood and brain of 53 dogs was 1.17 ± 0.09 and they concluded that the concentration of alcohol in the brain could always be closely predicted from that in the blood. Examination of the results from individual animals shows that variations up to 50 per cent from the average value occur, and it is therefore difficult to see how the authors could reach the above conclusion. In another investigation on post-mortem specimens, Ellerbrook and VanGaasbeek (1943) found the ratio between blood and brain to vary from 0.88:1 to 1.52:1. In those subjects known to have reached equilibrium, the ratio was close to unity.

From an examination of the results obtained by different workers it is apparent that it is not possible to predict accurately the brain alcohol concentration in any individual from a knowledge of the concentration of alcohol in the blood. Therefore, if the suggestion of Gettler and Tiber that the concentration of alcohol in the brain is the controlling factor in determining the degree of intoxication is correct, then wide variations must be expected if the degree of intoxication is assessed from the blood alcohol concentration. It must be remembered, however, that all work reported is based on either post-mortem examinations or animal experiments and it seems impossible to determine if these results reflect the true situation in the living person.
The foregoing results clearly indicate that there are factors which make it impossible to assess accurately the degree to which an individual is affected by a particular concentration of alcohol in the blood. In addition to the known existence of normal biological variation, factors such as tolerance to alcohol, variation in blood/brain ratio, and known ability of some persons to compensate partially for the effect of alcohol, may all contribute towards variation from the average effect observed. Despite these factors, the use of chemical tests in cases of driving under the influence of alcohol is increasing and it is of interest to examine some of the more recent studies in this subject.
3. CORRELATION BETWEEN IMPAIRMENT OF DRIVING AND BLOOD ALCOHOL CONCENTRATION.

The blood alcohol concentration at which 100 per cent of persons become clinically intoxicated has been reported by various workers to be in the range 0.200 - 0.300 per cent.

In most of these cases the criteria of intoxication demanded a clearly demonstrable impairment of physical and mental faculties such as is found in an advanced state of intoxication. Several other workers have shown that the functions of the central nervous system involved in driving a motor vehicle are affected at concentrations much less than those reported above (Bahnsen and Vedel-Petersen, 1934; Schmidt, 1934; Goldberg, 1943; and Newman and Abramson, 1941.). More recently Prag (1953) examined 100 subjects who had been charged with driving under the influence of alcohol. He also tested the effect of alcohol on the typing skill of experienced typists. He concluded that, at a blood alcohol concentration below 0.05 per cent, all persons were sober in the medico-legal sense and that, above 0.150 per cent, 94 per cent of the subjects tested were under the influence of alcohol. He expressed the opinion, now generally recognized as true, that the weakness of the chemical diagnosis is in the 0.05 - 0.150 per cent range.

The type of examinations which have been used in the above
experiments to determine the degree of impairment has been criticized on the grounds that the standards employed to detect the effects of the alcohol on an individual bear little relation to a person's ability to control a motor vehicle and that only gross signs of intoxication are detected. To overcome this objection several experiments have been conducted where the effect of alcohol on a person's driving ability has been determined in actual driving or simulated driving tests.

Bjerver and Goldberg (1960) investigated the effect of a low concentration of blood alcohol on the driving skill of a group of experienced drivers. Subjects were required both before and after the consumption of alcoholic beverages to drive through a "circuit" which included tests of steering, backing, parking, and general driving ability. A control group carried out the same experiment except that they consumed no alcohol. They found that at blood alcohol concentrations of 0.035 - 0.04 per cent there was a definite impairment of the driving ability of the subjects and that the presence of 0.04 - 0.05 per cent of alcohol in the blood resulted in a deterioration of 25 - 30 per cent in their ability to drive a car. They confirmed that impairment due to alcohol is present at these blood alcohol concentrations by use of the "flicker test" and the "blink test" which had been described by Goldberg (1943).

Recently Cohen, Dearmaley, and Hansel (1958) reported an experiment in which they attempted to introduce the measurement of psychological factors as a means of determining whether ingestion
of different amounts of alcohol caused any change in the margin of hazard and degree of risk involved in driving. They concluded that, even when the risk taken did not alter, the margin of hazard increased as the blood alcohol concentration increased. They also found that an effect of alcohol was to promote a tendency in the driver to over-rate his ability. In these experiments blood samples were not taken until at least half an hour after the completion of the driving tests and therefore these blood samples do not relate the individual's performance to his blood alcohol concentration at the time of the test. This may explain the authors' extraordinary statement that one subject was affected at a concentration of 0.002 per cent.

The use of a separate group of individuals without alcohol as a control in the experiment, as employed by both Bjerver and Goldberg, and Cohen et al., instead of the use of the "normal" behaviour of the same subjects as control, is open to criticism in that it introduces a further variable in an experiment where individual variation is already a complicating factor. This factor was removed in an experiment carried out by Loomis and West (1958) in which subjects were tested in a simulated driving apparatus. They used the tests performed by each subject before taking alcohol as the control for that subject, and calculated the degree of impairment due to alcohol from the variation from the normal performance of the tests. To avoid the complication of an improvement in performance
due to practice in carrying out the tests, the subjects were allowed
to accustom themselves to the apparatus on every occasion that an
experiment was conducted. In all, ten different subjects were each
tested on five separate occasions, and their blood alcohol
concentrations ranged from zero to 0.180 per cent. Loomis and West
concluded that there was a direct relation between blood alcohol
concentration and the impairment of function as measured by the
simulated driving tests. In some subjects impairment was observed
at a concentration of 0.03 per cent. At 0.100 per cent the
performance was 85 per cent of the control, and at 0.150 per cent it
had deteriorated to 75 per cent of the control. However, they also
found that, at a similar blood alcohol level on different occasions,
the one subject showed varying effects while, at similar concentrations,
different subjects varied in the degree of impairment observed.
Only one of the subjects showed obvious clinical signs of intoxica-
tion; the remainder showed such signs as talkativeness and removal
of inhibitions in the concentration range of 0.03 - 0.09 per cent
alcohol in the blood, and tiredness and slight impairment of co-
ordination in the higher range (0.100 - 0.178 per cent).

A similar experiment was reported by Drew, Colquhoun, and
Long (1958), who also concluded that there is a progressive
deterioration in driving performance as the blood alcohol
concentration is increased. Some deterioration in the performance
of the tests was observed at concentrations of 0.02 - 0.03 per cent,
the most noticeable impairment being in the operation of the
steering wheel.

In a comprehensive series of tests, Coldwell and his
colleagues (1958) examined 50 different subjects in actual driving
tests before and after the consumption of alcohol. The experiment
was similar to that reported by Bjorver and Goldberg, but each
subject acted as his own control by carrying out the test course
before the consumption of any alcohol. The driving performance of
the subject was measured from the time taken to complete a "driving
course" and from the number of mistakes made in negotiating the
course. The subjects were also clinically examined by two medical
practitioners who formed an opinion as to the ability of the subject
to control a car safely. The results showed that the driving ability
of over 50 per cent of the subjects was significantly impaired at a
blood alcohol concentration of 0.078 per cent, and that most of them
exhibited signs of impairment at a concentration of less than
0.120 per cent. Those subjects who did not show signs at the latter
level were heavy drinkers, but at a concentration of 0.160 per cent
these too showed impairment of their driving ability. In most
subjects, it was evident that general car handling ability deterior-
ated considerably even at low blood alcohol levels. Their results
also suggested that, in the lower concentration range, the alcohol-
accustomed driver could compensate for the effect of alcohol on
his driving but that, as the blood alcohol level rose above 0.100
per cent this ability was rapidly lost.

A comparison of the findings made from the results of clinical examinations (e.g., Jetter (1938) and Purves-Stewart (1937)) with those obtained from driving and related tests reveals that impairment in the subject's ability is detected at much lower blood alcohol levels in the latter experiments. There may be two main reasons for this difference. First, the clinical examination of the subject is usually made by an examiner who has no knowledge of the behaviour of the subject and this usually means that only gross impairment is detected, since the examiner must assume what is the subject's norm. In the driving tests, however, there is a measure of the performance of the tests with and without alcohol and small changes in the conduct of the tests are more readily detectable. Attention is drawn to this factor by Drew et al. (1968) who, in a discussion of their results, state: "The level of alcohol in the blood at which people are diagnosed clinically to be intoxicated, besides being variable, tends to be high in comparison with the concentration used here. This is not surprising, since an estimate of impaired behaviour is made in the absence of any criterion of normal behaviour for that individual, so that the impairment must be obvious before it is detected, and since it is known that people can compensate for their reduced efficiency over the short periods of time during which they are examined. It does not follow, however, that because no impairment is found in clinical tests, more complex
skills, like driving, will also be unaffected."

The second reason may be found in the experience of the examiner and also in the criteria of intoxication used. This is evident in a report of a survey conducted in Norway by Lofthus (1957), where two examiners made clinical examinations and blood alcohol tests on more than 800 persons charged with driving under the influence of alcohol. The survey was conducted over a period of several years. In its early stages, the least experienced examiner found fewer subjects to be under the influence of alcohol at comparable blood alcohol levels, but in the concluding stages of the work, their decisions showed little disparity. The difference in the conclusions reached by different medical examiners was even more marked in the experiments reported by Penner and Coldwell (1958) in which two medical practitioners examined the same subjects in connection with the driving experiments conducted by Coldwell and co-workers. One examiner concluded that 50 per cent of the subjects were impaired to the extent that their driving ability would be effected, while the other adjudged 74.4 per cent of the subjects to be similarly impaired. When these conclusions were compared with the results of the driving tests given to the subjects, (Coldwell et al., 1958), it was found that of the subjects who were adjudged as showing impaired driving ability, only 36 per cent of these were considered impaired by the first examiner and 61 per cent by the second.

They concluded that the medical examination used was not
sufficiently accurate to assess impairment in relation to driving a motor vehicle. Although in general the clinical examination was not sensitive enough, there were some subjects who showed no deterioration in driving ability and yet were considered impaired by the clinical examination. As a result of these experiments, they advocated that some means other than the clinical examination alone be used to determine the effect on driving ability due to alcohol.
4. DISCUSSION.

Although the results of the driving tests and related experiments have shown that a deterioration in performance due to alcohol occurs at blood alcohol concentrations which are much lower than that at which clinical signs of intoxication become evident, there are still widely divergent views on the relative value of the clinical examination and chemical tests in cases of driving under the influence of alcohol.

Loomis and West (1958) in discussing the relative value of the two tests in determining the condition of a person who is in a moderate state of intoxication state: "Clinical evaluation of such a subject offers no conclusive evidence of the less severe effects of alcohol. The present study indicates that impairment of function as determined by the simulated driving test is present when the blood alcohol concentration is in the range of 0.05 per cent and when gross clinical symptoms of intoxication may be minimal or absent".

Opposing this view is the recommendation contained in the report of a special committee of the British Medical Association (1958), which states: "... neither should a diagnosis (of intoxication) rely solely on the results of laboratory tests. An examining practitioner should base his opinion in the first instance solely on his clinical findings, modified subsequently, if necessary, in the light of the results of any laboratory tests."
That differences exist in the application of the results of chemical tests is seen in the different types of legislation which have been enacted.

In some countries, legislation has established that it is an offence for a person to drive a motor vehicle when his blood alcohol concentration is above a certain level, such as 0.100 per cent. Under this legislation the chemical test becomes the sole factor in determining whether an offence has been committed and it would seem that a clinical examination of the suspected person could add nothing to the proof. This legislation is not based on the premise that above the concentration limit set by law all persons are under the influence of alcohol, but that the driving ability of a sufficiently large percentage of people would be so affected by this concentration of alcohol in the blood as to make it undesirable for them to operate a motor vehicle.

Another form of legislation which has operated for several years in several states of the U.S.A. defines three broad zones of alcohol concentration in the blood. A concentration of below 0.05 per cent alcohol in the blood is prima facie evidence that the person was not intoxicated; between 0.05 per cent and 0.150 per cent the concentration is contributory evidence only, while a concentration above 0.150 per cent is prima facie evidence that the person was intoxicated. This type of legislation has been criticised on the grounds that all persons are not intoxicated at a concentration of
0.150 per cent (Rabinowitch, 1955) but, in the light of experimental work which has just been reviewed, this objection loses much of its weight. All subjects examined in these experiments showed that their driving ability has markedly deteriorated at a concentration of 0.150 per cent although they may not be considered clinically intoxicated at this concentration. It would seem that under this type of legislation a clinical examination should always be made in conjunction with the chemical test. While it may not detect small changes in the behaviour in the individual, the clinical examination will be of value in determining if injury or illness are contributory factors in the condition of the suspected person; if these factors are present, they may assist in establishing the innocence of the person.

Under legislation such as operates in Victoria (Crimes Act, 1958) where a blood alcohol concentration above 0.05 per cent is only contributory evidence, the value of the blood test is more limited. It does, however, provide evidence that the person has been drinking, and evidence of the minimum amount of alcohol that must normally be consumed to reach any given concentration. Under this legislation it would seem desirable that the chemical test be used in conjunction with a clinical examination.

It is therefore apparent that the value of the chemical test for alcohol in the body fluids in offences relating to driving under the influence of alcohol is dependent on the legislation under which the test is taken. The result of a chemical test should never
be used to determine that a person was affected to any particular degree, but only to indicate the probability that a certain state of intoxication existed at the time the sample was obtained from the person.
THESIS

AN INVESTIGATION OF LIMITING FACTORS IN THE USE OF BLOOD TESTS
AS EVIDENCE IN CASES OF DRIVING UNDER THE INFLUENCE OF ALCOHOL

PART I.  THE CHANGE IN BLOOD ALCOHOL CONCENTRATION FOLLOWING
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PART I.

THE CHANGE IN BLOOD ALCOHOL CONCENTRATION FOLLOWING ALCOHOL CONSUMPTION.
1. INTRODUCTION

Apart from the conclusion that it is not possible to assess accurately the degree of impairment of driving which a particular concentration of alcohol in the blood will produce in an individual, one of the main problems which has arisen in the use of the results of chemical tests in offences related to driving a motor vehicle has been the change in the blood alcohol concentration between the alleged offence and the time when a blood sample is taken. In practice it has been found that this time lag may be as long as four hours. The changes in blood alcohol concentration which may occur in this period are important from a medico-legal aspect, since it is only the alcohol in the tissues of an individual at any particular time which can influence his behaviour at that time.

The concentration of alcohol in the blood at any given time after the consumption of alcohol will depend on the rate of absorption from the gastro-intestinal tract and the rates of the processes of metabolism and excretion. Since these factors are dynamic they will result in a constantly changing concentration of alcohol in the blood, except for the period when the absorption and elimination (metabolism plus excretion) of alcohol are in equilibrium - that is when the blood alcohol concentration is at its maximum.
Since the relevant time in most cases of driving offences is not the time when the blood sample was obtained, but some period before this, it is important to know if it is possible to assess accurately the blood alcohol concentration in an individual at the time of the alleged offence. In general when a blood sample is taken, say, 75 minutes after a particular event, the concentration at the later time \( t_2 \) may be related to the concentration at the earlier time \( t_1 \) in one of three ways, as shown in Figure 1:

1. The alcohol concentration during this period may have risen (Curve A). Haggard and Greenberg (1934) calculated that absorption was not complete when the alcohol concentration was at its maximum in the blood. Hence, during this period of rising alcohol concentration it is evident that the rate of absorption exceeds the rate of elimination from the blood. This rise would therefore suggest that at least part of the drinking was fairly recent.

2. The alcohol concentration may have fallen during the period (Curve B). There are two mechanisms whereby this could occur:
   (a) The concentration may have increased for a short time, passed through the zone of maximum concentration, and then fallen to a lower value at the end of the period. This also suggests that some of the drinking was fairly recent.
   (b) The concentration may have been at or past the maximum value, and a fall in concentration has occurred throughout the 75 minute period. These circumstances suggest that the period of drinking was more remote and that the
process of elimination has predominated for at least 75 minutes before the blood sample was taken.

3. The alcohol concentration may be approximately the same at the time the sample was taken as it was 75 minutes previously (Curve C). The circumstances most likely to produce this phenomenon are that, during the 75-minute period, there was a period of rising concentration to reach the maximum, followed by a fall in concentration of similar magnitude to the previous rise.

It has long been known that the rates of absorption and elimination of alcohol may vary in different individuals. Smith and Glaister (1939) give the time required to reach the maximum concentration of alcohol in the blood as between 30 and 120 minutes after the finish of drinking, and the rate of metabolism as between 4 and 11 gram of alcohol per hour. These variations show the difficulty in assessing the alcohol concentration in the blood at some time before the sample was obtained.

From the medico-legal viewpoint, the situations as depicted in Curves A and B are most important since the concentration of alcohol in the blood at the time the sample was taken is different from the concentration present at the time of the alleged offence ($t_1$). This would mean that the degree to which the person is influenced by alcohol would be different at the time of taking of the blood sample than at the time of the alleged offence. In the example shown in Curve A, Figure 1, the person will normally be
affected to a lesser extent at $t_1$ than at $t_2$ and vice-versa for Curve B.

It is therefore apparent that the magnitude of the changes in concentration of alcohol in the blood after a period of drinking can assume importance in cases of "driving under the influence" of alcohol, particularly where an assessment is required in evidence of the concentration present in a defendant at some time before the taking of the sample.

One important consideration, which will affect the magnitude of the rise in the concentration after drinking, will be the rate of absorption of alcohol from the gastro-intestinal tract into the bloodstream and several factors have been reported as influencing this rate.

In 1919, Mellanby reported that the presence of food in the stomach increased the time required for the blood alcohol concentration to reach a maximum value and also decreased the maximum concentration attained after consumption of a given amount of alcohol. Widmark (1934) later made a similar observation and found that the effect was most apparent when the food had a high protein content. To account for these results, Widmark postulated that some of the ingested alcohol became bound to the protein and amino acids (e.g. glycocoll) in the food by formation of an ester, and that the "bound alcohol" was never absorbed as alcohol. This theory was shown to be incorrect by Haggard and Greenberg (1940) who found that
the effect of glycooool in rats was to retard the absorption of alcohol from the stomach, and that the lower maximum concentration observed was due to the increased metabolism which had occurred in the longer period of absorption. However, Goldberg (1943) pointed out that the mucous membrane of the stomach of the rat is different from that in man and that the mechanism of delayed absorption by glycooool may not necessarily be the same in man as in rats.

In 1940, Eggleton found that the amino acid, alanine, increased the rate of metabolism of alcohol in cats and that this increase could be responsible for the lowered maximum obtained when alcohol is taken with food. Eggleton discounted the Widmark theory of "bound alcohol" and showed that all of Widmark's results could be explained by an increase in the rate of metabolism.

Miles (1923) had claimed that the effect of food was to dilute the alcohol concentration of beverage in the stomach and that absorption was less rapid because weaker alcohol solutions are absorbed slower than more concentrated ones. This opinion is in agreement with the results of Berggren and Goldberg (1940) who found that the absorption of alcohol from the stomach was governed by the laws of diffusion and therefore a more concentrated solution of alcohol should be absorbed more rapidly than a weaker solution.

Similarly, it has been noted that the alcohol concentration of the beverage consumed influences the rate of absorption of alcohol. Mellanby reported that an increase in the concentration of
ingested alcohol produced an earlier and higher maximum concentration of alcohol in the blood; this effect was also found by Miles (1923). On the other hand, Widmark (1932) and Schmidt (1937) (cited Berggren and Goldberg, 1940) found that changes in the alcohol concentration of the beverage consumed did not produce any change in the rate of absorption. These observations will be discussed later in view of the results obtained in Experiment 3.

A further observation suggested, affecting the absorption of alcohol, was that absorption takes place more quickly in persons who are habituated to alcohol than in persons not accustomed to drinking. Schmidt (1934) found that the maximum concentration in the blood was reached in a shorter time in habituated persons than in abstainers. This was confirmed by Fleming and Stotz (1935) and Goldberg (1943), who also noted that the maximum concentration reached was higher in habituated persons.

In work which showed that the absorption of alcohol from the stomach follows the law of diffusion, Berggren and Goldberg (1940) found that the time at which the pylorus opened was an important factor in the rate at which the alcohol was absorbed from the gastro-intestinal tract. In experiments on both cats and humans they found that the rate of absorption increased when the pylorus was opened.

Although much work has been published on the effect of the above factors on the rate of absorption, little information is
available on the magnitude of the rise in blood alcohol concentration which can occur following various controlled conditions of drinking.

Weinig and Schwerd (1955) investigated the rise in concentration in the blood after the consumption of alcohol at various rates. They found that, after the finish of drinking, a rise in concentration of 0.09 per cent could occur when most of the alcohol was consumed in the final stages of drinking.

The Medical-Legal Committee of the Australian Transport Advisory Council (1967) made certain recommendations whereby it was suggested that the blood alcohol concentration at the time of an alleged offence could be calculated from the concentration found in the blood at some time after the alleged offence. From this report it would appear that the maximum rise in concentration which could occur after the completion of drinking would be 0.032 per cent. This report will be discussed later in the light of results obtained from the experimental work.

Under the legislation in force in Victoria which relates to the offence of Driving under the Influence of Intoxicating Liquor (Crimes Act, 1958), the changes in concentration which can occur in the period between the time of the alleged offence and the taking of the blood sample are most important.

Sub-section 1 of Section 408 of the Crimes Act states:
"... then, without affecting the admissibility of any evidence which might be given apart from the provisions of this section,
evidence may be given of the taking of a sample of blood from that person by a legally qualified medical practitioner within eight hours after the alleged offence, of the analysis of that sample of blood by a properly qualified analyst, of the percentage of alcohol expressed in grams per 100 millilitres of blood found by that analyst to be present in that sample of blood at the time of analysis, and of the opinion of that analyst, based on the analysis and the interval of time which had elapsed and the other relevant circumstances, as to the percentage of alcohol expressed in grams per 100 millilitres of blood which was present in the blood of that person at the time of the alleged offence

The clause which allows for the assessment of the concentration of alcohol in a person at a certain time has led to much legal argument. The difficulty in assessing the concentration in an individual at a certain time has already been shown and the general practice has arisen that the only opinion expressed by the analyst is whether or not the concentration would have been greater than 0.05 per cent at the time of the alleged offence.

In the Victorian case of Regina v. Baldwinson it was ruled by Woinarski J. that no evidence could be given of the result of the analysis of a blood sample obtained from the accused, unless the analyst could fulfil all provisions of Section 408 of the Crimes Act. The analyst in this case could not express an opinion as to the concentration of alcohol in the blood of the accused at the time of
the alleged offence and the evidence of the blood test was then ruled to be inadmissible.

A similar situation arose in the case of Benney v. Dowling (Victorian Reports, 1959), where the result of the analysis of a blood sample was held to be inadmissible for the same reason as in the above case. This matter then came before O'Bryan J. by way of an order nisi to review and it was held that the evidence of the analysis was admissible, even though the analyst could not fulfil all of the provisions of Section 408.

The question as to whether a person could have been at a higher or lower blood alcohol concentration at some time before the sample was taken is one which necessitates a knowledge of the magnitude of the increase and decrease in the blood alcohol concentration following a period of drinking. The work now described was undertaken to obtain information as to the magnitude of the changes in concentration which occur under various conditions of drinking, and to investigate some methods which have been suggested to overcome the problems incurred by the delay in obtaining a sample of blood following an alleged offence.

The work carried out was divided into four sections as follows:

1. Measurement of the increase in the concentration of alcohol in the blood after a period of rapid drinking.

2. A study of the effect of (a) the rate of drinking, (b) the
alcohol concentration of the beverage consumed, and (c) the presence of food in the stomach on the magnitude of the increases found in 1.

3. The determination of the rate at which alcohol is eliminated from the body.

4. An investigation of the use of breath and urine samples to determine if their use could help to overcome the problem of the delay in obtaining a blood sample.
2. EXPERIMENTAL STUDIES

General Description

In all experiments, the subjects were males, who ranged from near-teetotallers to heavy drinkers. When first tested, each subject was allotted a number which was retained throughout all the experiments, and his weight and drinking habits were recorded. Before each experiment began, a urine sample was obtained and analyzed; where no alcohol was present, the blood alcohol concentration was presumed to be zero. In some of the later experiments, an additional check was made by analysis of a breath sample. Apart from the experiment where the effect of food on the absorption of alcohol was investigated (Expt. 4), no food was eaten by the subjects for approximately three hours before the beginning of drinking.

Beverage Consumed

In the experiments where beer was consumed, the liquor was dispensed in seven fluid ounce units; the alcohol concentration of the beer used was found by analysis to be 5 per cent (volume in volume).

Where whisky was used, the unit dispensed was seven-eighths of a fluid ounce diluted with an equal volume of water or carbonated beverage. The whisky was found to contain 40 per cent alcohol (v./v.) and each unit therefore contained the same amount of alcohol
as the unit of beer; however, the alcohol concentration of the former unit was four times that of the latter.

In later experiments, where the blood alcohol concentration found by direct analysis was compared with the result obtained from analysis of a breath sample, some of the subjects drank brandy or wines instead of beer or whisky.

Collection and Analysis of Samples

A sample of blood from the cubital vein of either arm was collected into a tube containing potassium oxalate and sodium fluoride and shaken to prevent clotting. No preservative was added to the urine samples. Both fluids were stored in the refrigerator until they were analysed, which normally was within two days of the collection of the sample.

Blood and urine samples were analysed by the method of Kozelka and Hine (1941). This method has been found to be accurate and reliable and standard alcohol solutions could be analysed to within 0.005 per cent (Preston).

Breath samples were collected and analysed by use of the Breathalyzer (Borkenstein, 1957). The accuracy of this method will be discussed later.
3. EXPERIMENT 1.

MEASUREMENT OF THE INCREASE IN THE CONCENTRATION OF
ALCOHOL IN THE BLOOD AFTER A PERIOD OF RAPID DRINKING

This experiment was designed to determine the magnitude of the increase in blood alcohol concentration which could occur from the finish of drinking until the maximum concentration is reached. Since one of the most important factors affecting this increase would be the rate of absorption of alcohol into the blood stream, conditions were selected which would favor rapid absorption. These conditions were that the subjects had not eaten for approximately three hours before drinking commenced, and that they drank at their fastest possible rate. The period of drinking was also kept relatively short so that the metabolism and excretion of alcohol did not become an important factor; the drinking time exceeded 75 minutes in only three subjects (Nos. 18, 49, and 51) (see Table 1).

In four subjects (Nos. 1, 7, 15, and 32) alcohol was detected in the urine before the commencement of the experiment. When it was known that they had not taken alcohol for several hours, these subjects were included in the experiment, since the amount of alcohol which may have been in the stomach when the experiment began would not significantly affect the results.

Fifty-six subjects drank beer at their maximum rate and, within a few minutes of the end of drinking, a sample of blood
(3-5 ml.) was collected from the cubital vein of each subject. Three further samples were obtained at intervals for at least two hours after the finish of drinking. Urine samples were also collected at intervals and the subjects were asked to void the urine sample as near as possible to the time of the taking of a blood sample. In many cases, however, this was not possible and the samples were obtained whenever the subject wished to void urine.

Following the analysis of the blood samples, a graph of blood alcohol concentration versus time was drawn for each subject and the following information was derived:

(i) the concentration of alcohol \( c_o \) present in the blood at the end of drinking;
(ii) the maximum alcohol concentration \( c_{max} \) reached in the blood;
(iii) the rise in concentration \( c_{max} - c_o \) in the blood after the end of drinking;
(iv) the percentage of \( c_{max} - c_o \) which occurred in the first 15 minutes after the end of drinking;
(v) the percentage of \( c_{max} - c_o \) which occurred in the first 30 minutes after the end of drinking;
(vi) the time taken \( t_{max} \) after the end of drinking to reach \( c_{max} \) (expressed in minutes).

These results, together with the number \( A \) of 7 oz. glasses of beer consumed, and the time taken, \( T \) (in minutes), to consume the liquor, are recorded in Table 1. All concentrations are expressed as gram of alcohol per 100 millilitres of blood.
<table>
<thead>
<tr>
<th>Subject</th>
<th>A</th>
<th>T</th>
<th>$c_o$</th>
<th>$c_{max}$</th>
<th>$c_{max} - c_o$</th>
<th>Percentage of ($c_{max} - c_o$)</th>
<th>$t_{max}$</th>
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<tr>
<td>1 ±</td>
<td>13</td>
<td>60</td>
<td>0.144</td>
<td>0.226</td>
<td>0.082</td>
<td>49, 78</td>
<td>60</td>
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<td>2</td>
<td>8</td>
<td>45</td>
<td>0.042</td>
<td>0.099</td>
<td>0.057</td>
<td>61, 81</td>
<td>60</td>
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<td>3</td>
<td>6</td>
<td>45</td>
<td>0.095</td>
<td>0.100</td>
<td>0.005</td>
<td>80, 100</td>
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<td>4</td>
<td>10.5</td>
<td>57</td>
<td>0.123</td>
<td>0.153</td>
<td>0.050</td>
<td>23, 50</td>
<td>77</td>
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<td>4</td>
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<td>0.052</td>
<td>0.014</td>
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<td>6</td>
<td>7</td>
<td>58</td>
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<td>0.243</td>
<td>0.269</td>
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<td>0.035</td>
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<tr>
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<td>13 ±</td>
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<td>0.159</td>
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