MEETING OF THE INSTITUTE OF BREWING, HELD AT THE ROYAL INSTITUTION, ALBEMARLE STREET, LONDON, W.1, ON THURSDAY, 23RD OCTOBER, 1958

The President of the Institute, MR. M. A. PRYOR, in the Chair

HORACE BROWN MEMORIAL LECTURE*

REFLECTIONS ON SCIENCE IN RELATION TO BREWING

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Advances in brewing science made at the Brewing Industry Research Foundation are reviewed against the background of the pioneer work of Horace Brown and in relation to relevant work in allied fields. Particular advances have been made in studying problems of barley germination and in increasing knowledge of the enzymes of barley, malt and yeast. The bitter acids of hops have received intensive study, and there is real prospect of more efficient means of hop utilization being devised. Problems of beer stability are receiving careful investigation, and here again there are real hopes of useful progress being made. The importance is stressed of considering carefully the application of new scientific knowledge to the industry's problems, and attention is drawn to the potential utility of continuous processes.

BEFORE turning to my formal address, I would like to express to you, Mr. President, and to your fellow Officers of the Institute of Brewing, my sincere thanks for the great honour you have done me in presenting me with the Horace Brown Medal. Any claim that I may have for this distinction must surely rest upon the advances to brewing knowledge made by The Brewing Industry Research Foundation over the past 7 years and hence the award is collectively a tribute to the work of all members of its staff, both past and present. I would like also to take this opportunity of again thanking all my colleagues at Lyttel Hall for the unstinting help they have given me at all times. I would therefore ask your permission for this medal to repose at the Foundation as a permanent memorial to the name of Horace Brown.

GENERAL

Since research was started at Lyttel Hall, diverse series of investigations have been undertaken, many of which are closely linked with work initiated by Brown himself, a scientist whose genius has not only stood the test of time but one whose stature has indeed become still more apparent as we have come to appreciate the full significance of the problems which he attacked with such conspicuous success. As the late Professor H. E. Armstrong has so rightly stated "Horace Brown in fact did for brewing what Lister did for surgery."

Although it is believed that the art of brewing has been known for at least 8,000 years, it was not until the year 1837 that Cagniard-Latour, following upon observations made by Spallanzani in 1776, suggested that the process of fermentation was intimately associated with the budding of yeast cells. The work of Cagniard-Latour was considerably expanded by Schwann in 1839, who further suggested that the growth of yeast cells was dependent upon the presence of sugar which acted as their food material.

The view that yeast as a living agent played any part in the transformation of sugars into alcohol was derided by von Liebig and many other leading chemists of the day, who envisaged the production of alcohol from sugar as a purely chemical process depending upon a post-mortem decomposition of the

* See also this *Journal*, 1958, 457.

dead yeast. This was generally accepted until 1857, when Pasteur advanced convincing proof concerning the association of fermentation with living matter. His first memoir published in 1860 dealt with the lactic fermentation which, he observed, depended upon the growth of a rod-like organism quite distinct from the yeast cells proliferated during alcoholic fermentation. These researches, which were continued during the next twenty years, not only opened a new chapter of scientific enquiry but at the same time laid the foundation of the science of bacteriology. Further, during this period Pasteur was led to the view that each type of fermentation was correlated with a specific organism while, from a study of the butyric fermentation, he advanced the challenging new concept of anaerobic life, a concept which immediately raised a storm of opposition but which has been completely vindicated by the passage of time. In 1866 Pasteur's comprehensive investigations on wine were published under the title *Études sur le Vin*, while in 1876 appeared his *Études sur la Bière*, in which he included all the researches on this subject which had occupied his time between the years 1871–76.

It is needless for me before an audience of brewers to discuss in detail the far-reaching effects of Pasteur's inspiring investigations on the technology of brewing. I have indeed mentioned them only in order to link them with Horace Brown's own researches which he has recorded in his fascinating lecture entitled *Fifty Years' Experience of Science in Brewing Practice*, published in 1916 (this *Journal*, 1916, 267). In this review he gives an account of how, when his study of microscopic methods had just been initiated, Pasteur's *Études sur le Vin* came belatedly into his hands in 1870. In his own words he states:

> "The immediate effect was that of a ray of light piercing the darkness and illuminating a new path into the unknown. It is true that the work dealt only with wine, but it was at once evident that the new principles must be equally applicable to beer brewing, and from that moment I turned my attention with renewed energy to microscopical work, fully confident that I should thereby obtain an answer to the many questions which I had been asking myself for the past three or four years."

About the year 1873 Horace Brown, who had joined Worthington's in 1866 as junior brewer and was now one of the Joint Managers, obtained the services of John Heron as his private assistant and started research with him on the chemistry of starch. Curiously enough this work proved unsatisfying to him and was finally abandoned about 1900 in favour of more fruitful investigations. In 1883 Heron was succeeded by George Harris Morris and now commenced an association which, for the next two decades, was to prove highly productive and lead to the publication of a series of memoirs of outstanding scientific merit.

With the departure of Brown to London in 1894, the great Burton school of brewing science came to an end. Böttinger, a pupil of von Liebig in Giessen and appointed to Allsopps in 1845 had left Burton to return to Germany in 1866. Peter Griess, brought to Burton by Böttinger in 1859, and famous to us now as the discoverer of the diazo-compounds, had died in 1888. Adrian Brown, a half-brother of Horace and a chemist at the brewery of Messrs. Salt & Company, left Burton in 1899 to occupy the new Chair of Brewing and Malting at the Mason College, Birmingham, while O'Sullivan, who was appointed to Bass & Co. in 1867 and will always be remembered for his work in unfolding the transformation of starch into maltose, died in 1907.

Looking back over the years it is difficult to understand how the Burton brewers of those days could have been so shortsighted in failing to follow up the many important scientific and technological contributions initiated by this brilliant group of specialists. Had they done so, the brewing industry of this country might well to-day be in control of many important ancillary industries covering a wide range of industrial fermentations, including also the new and invaluable field of antibiotics.

With the stimulating background of Burton in mind it was with keen anticipation and enthusiasm that I set out in 1948 to plan a co-ordinated programme of work in which basic science would be firmly linked with the many urgent problems of the Industry. The time was especially opportune, for recent advances in experimental techniques such as chromatography, infra-red and ultraviolet spectroscopy, the use of tracer elements, etc., made it possible to investigate with high hope of success many brewing problems, the solution of which had been denied to our predecessors.

It was not to be expected that the formation of a central research establishment for the industry would be received with acclamation by all practical brewers, but this may possibly be attributed to lack of precise information concerning its functions. Actually, the aims of B.I.R.F. were clearly laid out in its first Annual Report published in 1951 in which it was stated that:

> "The Foundation is designed primarily for the investigation of the many basic problems which confront the Brewing Industry and the solution of which is beyond the resources of the individual brewery. It is not intended to usurp the functions of the individual brewery's own laboratory on the one hand, nor of the brewing consultant with his intimate knowledge of local conditions on the other. Rather has it a specific function, just as have those Research Associations of this country whose names are linked with other great industries. This function is to acquire through its own researches and by its contacts with allied industries, the Universities and Government Departments, a wealth of knowledge and experience which, subject to the legitimate interests of individual breweries, shall be available for the benefit of the industry as a whole."

Again, it has been stated from time to time that the intrusion of science into the realms of brewing could be detrimental in tending to lead to the production of beers in which the art of the individual brewer would be lost. Such fears have, of course, proved completely groundless for, without in any way infringing upon the art of the brewer, the application of science has, as could be expected, brought to light many aspects of the brewing process hitherto completely unsuspected. Examples which come to mind immediately are, for instance, the importance of the leucoanthocyanins in relation to non-biological hazes in beer, the impact of new knowledge concerning the α resins upon hop utilization or again the unravelling of some of the mysteries of dormancy or yeast flocculation.

Every industry, if it is to survive, must be in a position to adapt itself to changing circumstances in the world at large. The increasing cost of the brewing industry's raw materials such as barley, hops and fuel, together with the high costs of building and equipment, alone necessitates this. Another important factor based on world economics is the need from time to time to accept new materials. An apt example is the replacement of Spratt-Archer and Plumage-Archer barleys by Proctor, a barley which is acceptable both to farmers as stock-feed and to brewers as a good malting barley. Despite the many desirable properties of this barley I have little doubt that, from among some of the new varieties now being produced by the Plant Breeding Station at Cambridge or through the E.B.C., there will ultimately emerge even more generally acceptable barleys. In mentioning Proctor I would stress the novel and detailed work carried out at the Foundation which I believe helped in no small degree in securing its ready acceptance. This is, however, only a single example of the very considerable collaborative effort which is now a well-established part of the work at Lyttel Hall. I refer here to the examination of new barleys and malts, numbering some 20 to 30 samples per year, which come to us from the N.I.A.B. and from the E.B.C. I do not need to stress the point that the work involved covers both conventional and chromatographic analysis of barleys, malts and worts and that, in appropriate cases, it includes many malting and brewing trials. All this reflects a tremendous change when one recollects that in 1948 the Barley Committee had ceased to function. To-day this Committee, which has the full backing of farmer and maltster alike, now plays an incisive part in the work of the Institute.

What I have said about barley is, in large measure, applicable to hops, the evaluation of which prior to the creation of B.I.R.F. lacked rationalization. The situation is now very different, for a programme is agreed annually between the Foundation and Wye College whereby selected new varieties of hops are carefully examined for their brewing qualities both in the laboratory and in the brewery itself. In all these matters it is evident that the Foundation has become a focal point for the Industry as a whole and here the bi-annual meetings of the Scientific and Technical Advisory Committee are playing an increasingly conspicuous part. Indeed, there is little doubt that the Foundation is to-day in the forefront of progress in brewing science over a vastly wider field than has ever before been covered by a single brewing research establishment.

Some Specific Topics

And now I would like to illustrate certain of the general matters which I have been discussing by brief reference to selected topics which still await complete elucidation but to

which answers must be found if complete control of brewing operations is finally to be achieved.

Barley and malt.—Brown & Morris in their remarkable paper entitled *Researches on the Germination of some of the Gramineae* (*J. chem. Soc.*, 1890, **57**, 458) gave for the first time a convincing account of certain of the chemical and morphological changes which take place in the barley grain during the early stages of germination. Of these perhaps the most significant was the observation that isolated barley embryos were able to bring about the conversion of maltose into sucrose, a sugar which plays a seemingly central role in cell metabolism. B. H. Kirsop & J. R. A. Pollock (*Proc. Eur. Brew. Conv., Copenhagen*, 1957, 84) have now extended this work and have observed that, provided the embryo has been retained intact in the corn for a period of three days after germination has begun, modification of the endosperm will continue to completion even though the embryo be then removed (this *Journal*, 1958, 227). The dry endosperm so obtained contains, however, only a small residue of β-amylase and it would thus seem that one specific function of the growing embryo is to synthesize this and other enzymes and secrete them continuously into the endosperm. It was against this background that a search for a growth inhibitor, which would restrict the root-growth which accounts for 5% of the loss during the conversion of barley into malt, was initiated. A. H. Cook & Pollock (this *Journal*, 1952, 216) confirmed certain work by M. van Laer & P. Froschel (*Bières et Boissons*, 1942, **3**, 136) showing that the liquors obtained on steeping barley in water are inhibitory to its germination. In a later paper Cook & Pollock (this *Journal*, 1954, 300) isolated a phenolic acid, vanillic acid, from barley steeping liquors and showed that, while it had no action on the earliest phases of the germination of barley, it exerted an inhibitory action against root growth at a later stage in the process. Attempts to find still more powerful agents revealed that the use of coumarin at a concentration of about 100 p.p.m. was most effective, giving between 1–3% more malt with satisfactory mashing characteristics. Although coumarin has been and indeed is still employed as a flavouring agent in a variety of foodstuffs and is itself present as a natural constituent of barley (C. van Sumere, H. Hilderson & L. Massart, *Naturwissenschaften*, 1958, **45**, 292), it has now been reported that, applied in very large doses, it can prove toxic to animals. As a consequence of this and because of a distinct flavour which it imparts to the resultant malt, further work on its application as a rootlet inhibitor has been discontinued, although investigations are still in hand in the hope of finding some other suitable compound and one at the same time wholly satisfactory as regards toxicity and flavour. It is pleasant to record that parallel research on this subject by A. Macey & K. C. Stowell (this *Journal*, 1957, 391) has meanwhile led to the discovery that potassium bromate can restrict malting loss by from 1–2% and that in this case both rootlet-growth and respiration are involved.

Reverting now to β-amylase, a renewed examination has been made of this enzyme (Pollock & A. A. Pool, this *Journal*, 1957, 151). Whereas its discovery in barley, as distinct from malt, is due to Kjeldahl, the first Director of the Carlsberg Laboratories (*C. R. Lab. Carlsberg*, 1879, **1**, 129), it was J. S. Ford & J. M. Guthrie (this *Journal*, 1908, 61) who made the first comprehensive study of its extraction from barley grist and showed that a substantial enhancement of activity resulted when salts were added to the extracting fluid. These authors further observed that a still greater increase occurred in the presence of a proteolytic enzyme such as papain. From this and the results of other workers (*e.g.*, M. F. Dull & R. C. Swanson, *Cereal Chem.*, 1941, **18**, 113; E. Sandegren & N. Klang, this *Journal*, 1950, 313; V. L. Erlich & G. M. Burkett, *Cereal Chem.*, 1950, **27**, 423) it became clear that barley contains both free and chemically bound or "latent" enzyme. The β-amylase from this latter component has now been extracted from barley by means of thioglycollic acid and suitably concentrated; it was obtained as a white solid which, when subjected to zonal electrophoresis, behaved as a single entity. The importance of this observation lies in the possibility of now gaining precise information on the breakdown of starch by examining the action of an individual β-amylase completely free from any trace of the closely related α-amylase. This latter, which is present in negligible amounts in barley, is rapidly formed when growth begins and continues to increase in amount almost until the green malt is kilned.

Both α- and β-amylases play major roles in bringing about the hydrolysis of starch, but it must nevertheless be stressed that amylases derived from different sources are not necessarily identical in physical properties, a fact not perhaps surprising when one bears in mind that, like most enzymes, they are proteins of high molecular weight.

In order to gain some closer insight into the mode of action of each amylase, it is first necessary to consider briefly some of the outstanding characteristics of starch itself. It is a well-established fact that this polysaccharide is laid down in the growing plant in the form of granules which vary from species to species, but the precise manner in which it is built up is still a matter of conjecture. It is known that plants have the power to synthesize starch from many simple sugars and enzymic synthesis of one component *in vitro* has been achieved by incubating glucose 1-phosphate with potato phosphorylase (C. S. Hanes, *Nature, Lond.*, 1940, **145**, 348; *Proc. Roy. Soc.*, 1940B, **128**, 421). Natural starch is made up of two components known as amylose and amylopectin, and it is the former constituent which gives the characteristic blue colour with iodine; amylopectin alone produces only a reddish colouration. Starches vary quite considerably in the proportions of these two components. While ripe barley starch and potato starch both have an amylose content of about 25% of the whole, in waxy maize starch it comprises only about 2%. The molecule of amylose has a molecular weight of the order of 200,000 and consists of straight chains of a thousand or more glucose units linked by α-1·4-bonds and arranged probably in a helical conformation. Amylopectin, on the other hand, is a much larger molecule with a molecular weight of 1,000,000 or even more, in which smaller glucose chains containing only some 24–25 units are linked to one another through α-1·6-bonds, thus producing a molecule with a highly branched structure (Fig. 1).

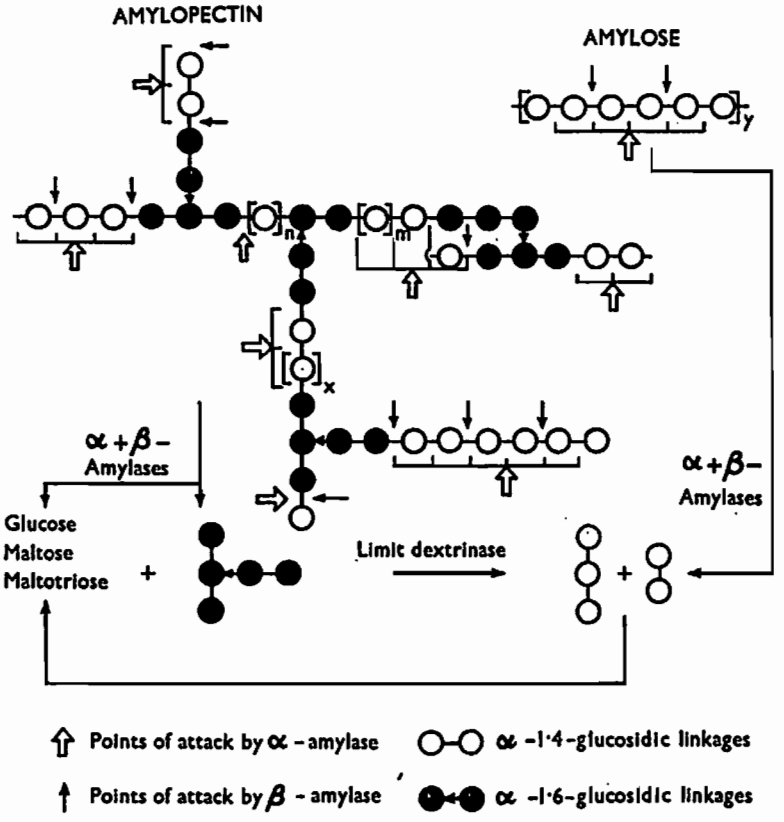


Fig. 1.—Starch components and their degradation by malt enzymes.

Although it was thought until recently that the starch of barley was identical with that of malt, it has now been established (G. O. Aspinall, E. L. Hirst & W. MacArthur, *J. chem. Soc.*, 1955, 3075) that the part of barley starch which becomes solubilized for purposes of growth and respiration during malting consists mainly of the outer branches of amylopectin, with the result that the number of glucose units per branching point becomes reduced to 17–18.

If we now turn to consider the mode of action of α- and β-amylases, it is found that the latter enzyme attacks only the straight portions of the polyglucose chains in starch, producing maltose as the sole low-molecular-weight product. While therefore it can theoretically bring about the almost complete breakdown of amylose, it is quite unable to circumnavigate anomalies such as the branch points in amylopectin, and its action on this component is brought to a halt at a distance of one or two glucose units away from the 1·6-glucosidic cross linkages. As a consequence, the main product, apart from maltose, is still a large molecule consisting of a branched chain residue with a molecular weight of about 50% of that of amylopectin. On the other hand, α-amylase attacks both amylose and amylopectin with the production of relatively small molecules. With the linear amylose an initial vigorous attack slackens when about 17% of the glucosidic 1·4-links have been ruptured, the principal products being short linear dextrins which are only slowly hydrolysed further to maltotriose, maltose and a small amount of glucose. In the case of amylopectin its breakdown is more complex, yielding firstly short linear dextrins from the ends of the chains. Further, as α-amylase is able to by-pass branch points, low-molecular-weight dextrins also result in which the α-1·6-glucosidic linkages remain unimpaired. These in turn are further shortened by hydrolysis to yield finally limit dextrins consisting of 3–7 glucose units, which resist fermentation by ordinary brewing yeasts. This is approximately the situation in the mash-tun but, because of inactivation of the enzymes by heat, amylolysis does not proceed to the limit and highly branched dextrins containing an average chain length of up to 13 or more glucose units have been isolated from an infusion wort (G. Harris & I. C. MacWilliam, this *Journal*, 1958, 395). Actually the story of the malt enzymes is still more complex, for it is possible to hydrolyse starch to simple sugars by scission of all cross links at a temperature of about 40° C. This is effected by means of a further enzyme present in malt, known as limit dextrinase. This enzyme can attack 1·6-linkages but is ineffective under the mashing conditions used in this country, as it is very rapidly destroyed at the temperatures so employed.

Yeast.—Turning now to the enzymes of yeast, some elegant chromatographic work carried out at the Foundation has resulted in the isolation of the maltase of a typical brewing yeast with a degree of purification which has, I believe, never before been achieved. The degree of concentration of the enzyme is between 300 and 400 times and the product so obtained would appear to be practically homogeneous as judged by its behaviour in the ultracentrifuge. It has also been shown that the maltase of a super-attenuative strain of *Sacch. cerevisiae* is chemically distinct from the corresponding enzyme of an ordinary brewing strain. The maltase of *Sacch. uvarum* is inactive towards maltotriose, a fact which would indicate that this latter organism contains yet another enzyme of higher specificity than that possessed by the brewing yeasts.

This brings me to the fermentation process itself, and here I would remind you that carbohydrates may be metabolized either in the absence or in presence of oxygen. The more important process in brewing is the anaerobic breakdown or, as Pasteur himself put it, "life without air." The transformations of carbohydrates comprise a series of complex but wonderfully balanced biochemical processes which provide the major energy requirements of the living cell. Although the enzymes which hydrolyse the more complex carbohydrates to simple substrates suitable for fermentation are, in most yeasts, mainly localized within the cell, certain exceptions are known. For example, invertase is associated with the surface of the cell, with the result that the hydrolysis of sucrose can occur extracellularly. In some cases at least a special enzyme mechanism brings about the transport of specific molecules from the growth medium to within the cell. As a result of work carried out by J. J. Robertson & H. O. Halvorson (*J. Bact.*, 1957, **73**, 186) it seems probable that a mechanism of this type is operative in the

case of maltose. Extension of this work by A. W. Phillips at B.I.R.F. points to a similar control mechanism existing for maltotriose.

The Gay-Lussac equation:

$$C_6H_{12}O_6 = 2\ C_2H_5OH + 2\ CO_2$$

although stoichoimetrically adequate expresses only overall carbohydrate metabolism.

oxidation-reduction systems together with phosphate transfer reactions. Of these nucleotides, coenzyme I (Fig. 3) first observed by A. Harden & W. J. Young in 1905 and ultimately synthesized by A. R. Todd in 1956 plays a significant role, as also does adenosinetriphosphate (Fig. 4) which functions as a transporter of energy-rich phosphate bonds

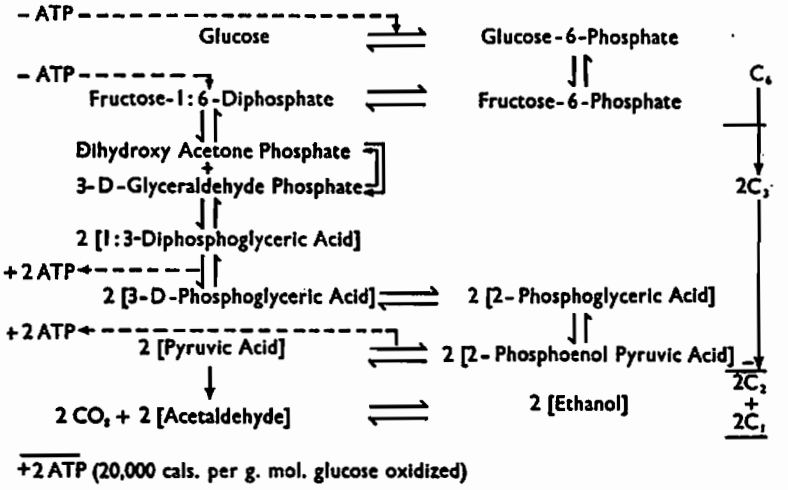


Fig. 2.—The fermentation scheme according to Embden-Parnas-Meyerhof.

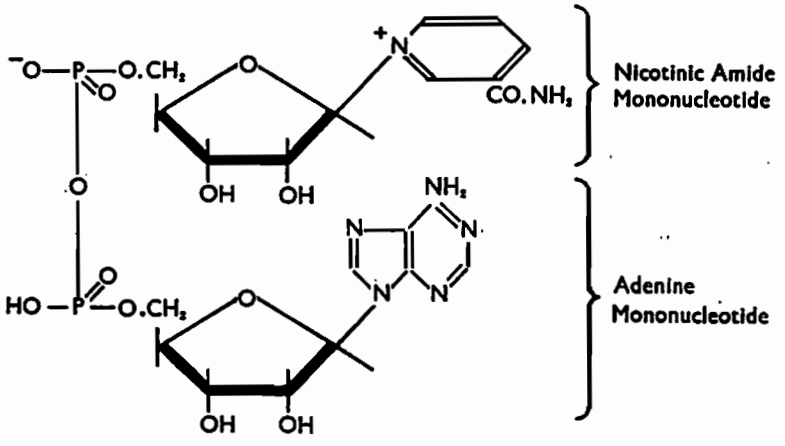


Fig. 3.—Coenzyme I, or adenine-nicotinamide dinucleotide, sometimes loosely termed adenine-pyridine dinucleotide or APDN (also PDN or DPN).

The detailed series of reactions actually followed is known as the Embden-Parnas-Meyerhof route (Fig. 2) which accounts for all the known facts of alcoholic fermentation of glucose and fructose. Nucleotides play an outstandingly important part in carbohydrate metabolism, which involves enzymic and hence supplies the driving force for most of the synthetic reactions involved in cell-growth. Attention at the Foundation became focused upon the constituent purine bases, adenine and guanine from wort (Harris & R. Parsons, this *Journal*, 1955, 29). Accordingly, a study of the formation of these two

compounds on mashing and their subsequent assimilation by yeasts was put in hand. The free bases were rapidly taken up by brewing yeasts, adenine however in preference to guanine (Harris & Parsons, this *Journal*, 1957, 227). An investigation of other yeasts revealed considerable differences in the pattern of assimilation, guanine being utilized from wort almost exclusively by the wild yeast, *Pichia membranaefaciens* (Harris & Parsons, this *Journal*, 1958, 33). The fate of the purines and related pyrimidines within the yeast cell is now being followed with a view to ascertaining their effect on yeast growth. For this purpose, methods for analysing the nucleotides of yeast have been developed by Harris & Parsons (this

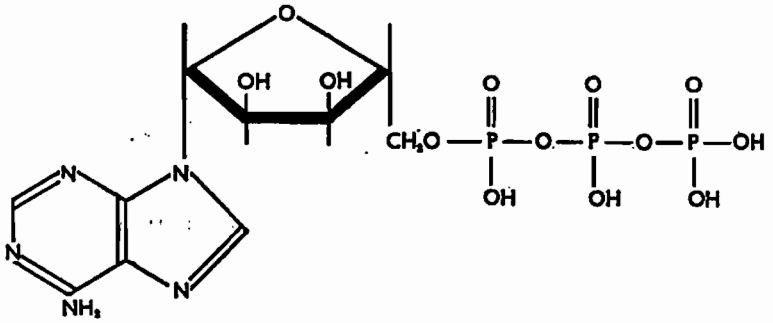


Fig. 4.—Adenosine triphosphate (ATP).

Journal, 1958, 308) with the result that certain nucleotide-peptide complexes have been recognized and a representative member has been isolated for structural study.

I have dealt with the subject of starch degradation and fermentation at some length as I feel that here are fields rich in promise for advancing fundamental knowledge, while they also possess considerable potential economic scope.*

Hops.—I would like to turn now to certain other fields of investigation which are being examined at Lyttel Hall and here, firstly, I would mention some of the recent work which has been carried out on hop constituents and their functions in brewing. Up to 1952 it had been generally assumed that the antiseptic and bittering properties of hops were due to the presence of a substance known as humulone, at that time thought to be the main constituent of the α acids. Over the past few years it has become clear, however, that, together with humulone, the α acids contain at least two other closely related compounds, cohumulone and adhumulone (Fig. 5). Each of these compounds has now been isolated in the pure state, structures elucidated and synthesis achieved. (Humulone: W. Riedl, *Brauwissenschaft*, 1951, **52**, 85, 133; *Ber. dtsch. chem. Ges.*, 1952, **85**, 692; *Ann.*, 1954, **585**, 38; cohumulone: G. A. Howard & A. R. Tatchell, *Chem. & Ind.*, 1954, 514; adhumulone: *idem.*, *ibid.*, 1954, 992). With this background, Howard & Tatchell (this *Journal*, 1957, 138) have made an extensive survey of a wide range of hop varieties which has revealed some striking facts of considerable practical importance. For example, whereas adhumulone accounts for approximately 15% of the total α acids, cohumulone varies in different groups of hops from 20% to as much as 65%. Among the hops most liked in this country the cohumulone content is about 30% as compared with, say, Hallertau hops in which it falls to 20%, while in America the favoured varieties contain from 40 to 50% of this constituent. It is not, however, the α acids themselves which account for the bitterness and bacteriostatic properties of beer, but their transformation products, known as *iso*-compounds, which are formed during the boiling stage of the brewing process (Howard, C. A. Slater & Tatchell, this *Journal*, 1957, 237). The changes which the α acids undergo during wort boiling can be readily reproduced in the laboratory and by starting with individual pure α acids the corresponding *iso*-analogues can be prepared. This has rendered it possible to evaluate the degree of bitterness conferred on a beer by each *iso*-compound and

* Further aspects of this are considered in detail in Dr. Harris's interesting paper entitled *Significance of Carbohydrate Research in Malting and Brewing* (this *Journal*, 1958, 390).

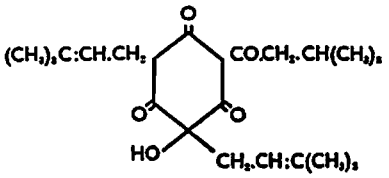
from this the interesting fact has emerged that, whereas only about 20% of the humulone is utilized in brewing, with cohumulone the bittering value is as high as 40%.

Assuming, as seems almost certain, that the *iso*-compounds are solely responsible for bitterness and that they in turn are derived from the α acids, the bittering efficiency of hops is conveniently expressed by the formula:—

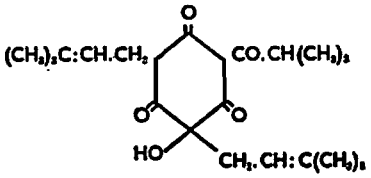
$$\%\ \text{utilization} = \frac{\text{concentration of } \textit{iso}\text{-compounds in beer} \times 100}{\text{concentrations of } \alpha \text{ acids added to wort.}}$$

In British brewing, for a normal hop rate of 1 lb. per brl., the utilization values range from 15–29%, whilst for higher rates the utilization can be as low as 10% (R. D. Hall, *Proc. Eur. Brew. Conv., Copenhagen*, 1957, 314). Among the reasons for this low utilization value are firstly the slow rate of extraction of the α acids from the hops and, secondly, the fact that once extracted a large proportion is immediately precipitated together with the protein "break." The results of numerous trials carried out at B.I.R.F. have shown that hop utilization can be increased by several practical methods such as (*a*) lower infusion mashing temperatures, (*b*) brewing with steamed hops and (*c*) higher wort temperatures during hop extraction. None of these, however, increases the efficiency beyond 30%, and it thus becomes clear that if a higher degree of utilization is to be obtained, a revolutionary departure from traditional practice will have to be adopted. It has now been demonstrated that the addition of preformed *iso*-compounds to fermenting sweet wort yields a beer closely comparable in taste to beer brewed in the conventional manner, but the percentage utilization is raised to between 50 and 60%.

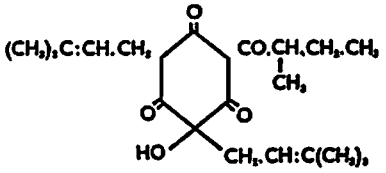
So far as the brewer is conerned, the quality of hops depends not only upon their bittering value but also upon the aroma due to the presence of hop oil which varies in different varieties of hops from 0·2 to 1·7% of the hop cone. Using the technique of gas chromatography it has been confirmed that the oil is a complex mixture containing in addition to the terpene hydrocarbons, myrcene, farnesene and humulene, various oxygen-containing components such as esters of fatty acids, ketones and alcohols. At the present time over 50 individual substances have been detected (Howard, this *Journal*, 1957, 126) but in normal brewing practice many of the more volatile components are removed during boiling in the copper. Another interesting feature concerning hop oil is the remarkable rise in content which occurs during a relatively short period of



HUMULONE



COHUMULONE



ADHUMULONE

Fig. 5.—Components of the α acid fraction of hops.

ripening. In a random case (Bullion, 1956), the oil content rose from 0·2–1·4% over 4 weeks prior to picking, with pronounced changes in its composition over this same period.

Beer.—I have already referred to the production of non-biological hazes in beer, a problem which adds considerably to the difficulties experienced by the brewer in dealing with bottled beers. Horace Brown suggested that non-biological haze was due to the formation of a protein-tannin complex, but there the question was largely left. Such work as has since been done on this subject has been largely directed to attempts to identify the protein fraction responsible, but few tangible results have been recorded. At B.I.R.F. attention has been focused with considerable success upon the tannin aspect of the problem. "Tannin" is a generic term and covers a wide range of natural compounds of diverse structure. It was shown (W. I. Bengough & Harris, this *Journal*, 1955, 134) that polyphenols derived both from hop cones as well as from husks of barley contribute to the formation of the complexes with proteins. Detailed investigation of these compounds has pin-pointed the leucoanthocyanins as the most important constituents causing haze development (see, *e.g.*, Harris & R. W. Ricketts, *Chem. & Ind.*, 1958, 686). Interesting as these observations are to the scientist they would obviously be of no help to the brewer if means could not be found for removing these unwanted substances from wort or beer. It would now seem that an answer to the problem may have been obtained. This depends upon the selective adsorption of the leucoanthocyanins on certain forms of *Nylon*, whereby a beer with greatly increased stability is produced without detriment to any other property.

Other topics.—As I have already mentioned, my subject is too wide to enable me to do more than draw attention to certain perplexing matters upon which science is now throwing light. In this category a more precise understanding of yeast is urgently required. One of the most important practical aspects of this is concerned with the problem of controlling and standardizing the quality of yeast for use in brewery fermentations. New analytical methods have been developed which serve to characterize and count each of the various types of yeast and bacteria which are found in pitching yeast. The organisms are conveniently grouped under three headings comprising (i) wild yeasts, (ii) brewing yeasts and (iii) bacteria. In the case of wild yeasts E. O. Morris & A. A. Eddy (this *Journal*, 1957, 34) showed that a quantitative recovery of various wild yeasts added deliberately to brewing yeasts could be obtained with the aid of an agar medium containing lysine (L. S. Walters & M. R. Thiselton, this *Journal*, 1953, 401). An examination of pitching yeasts from various breweries has revealed the presence in most samples of wild yeasts in the proportion of about one cell per million cells of pitching yeast (B. L. Brady, this *Journal*, 1958, 304). Among the wild yeasts observed, *Pichia membranaefaciens*, *Candida mycoderma*, *Torulopsis colliculosa* and *Torulopsis inconspicua* were of common occurrence, and a total of thirteen other species was observed on different occasions.

A more difficult problem is presented by the group of rather similar strains of *Sacch. cerevisiae* which usually form the major part of a pitching yeast. In this case the flocculation characteristics present a direct means of classification and, by making use of varying responses of different yeasts to selected experimental conditions, a general scheme has been evolved whereby mixtures of yeasts may be empirically analysed (J. S. Hough, this *Journal*, 1957, 483). Examination of a considerable number of brewing yeasts in this way has revealed that, whereas the composition of the mixture in some cases remains substantially consistent over long periods, in others difficulties in fermentation or fining can often be traced to a progressive change in the make-up of the mixture. By enabling the brewer to maintain the constancy of the pitching yeast, by supplementing it from time to time with those original strains which under his particular conditions have tended to become outgrown, many fermentation difficulties can be eliminated.

Conclusion.—Apart from the investigations to which I have made reference, there is a wide range of other fascinating researches in progress both in this country and elsewhere of which the implications cannot as yet be fully assessed. It is, however, of still other matters that I wish in conclusion to refer. For many years now brewers have recognized the changing Trade conditions in this country and, as a recent article in *The*

Times newspaper entitled *The Brewers Work Wonders* clearly indicates, they have up to the present been outstandingly successful in overcoming the difficulties of a contracting market. There is one trend of modern times which so far has made little impression upon traditional brewing. I refer here to the adoption of continuous brewing processes. Although batch-wise operations of mashing, boiling and fermentation are still universally employed, economically they leave much to be desired—especially in respect of capital costs, economy of space and fuel requirements. As you know, the Foundation has, over the past few years, been engaged in examining the practical possibilities of making brewing a continuous operation. A marked degree of success has been reached on the laboratory scale and, although the translation to full-scale brewing may meet with many unforeseen difficulties, it seems not unlikely that we are now witnessing the dawn of a new era, in which science and the brewer's art will be closely interwoven to an ever increasing extent. I am confident that in this new development the Foundation, under the direction of my successor, Dr. A. H. Cook, F.R.S., and his excellent team of workers, will continue to play an important part in extending the frontiers of scientific knowledge to the ultimate benefit of the Brewing Industry of this country.