MICROSCOPIC LABOURERS AND HOW THEY SERVE US.

By PROFESSOR PERCY F. FRANKLAND.

OF all the brilliant scientific discoveries which the nineteenth century has witnessed there are perhaps none which possess more general interest and fascination than the marvellous revelations concerning those low forms of life which, although invisible to the naked eye, infest all our surroundings and have such an extraordinary potentiality for good or evil ; appearing sometimes as our friends and faithful servants doing the work which they are bidden without a murmur, whilst at other times they oppose us as implacable foes and defy our power and ingenuity.

It is only during the last few decades of this age that we have become accurately acquainted with the nature and works of these minute living forms, which we now generally designate as *micro-organisms*, *microbes*, *germs*, or *bacteria*. For much of this knowledge, and more especially for the groundwork of it, we are indebted to the indefatigable energy and masterly genius of Louis Pasteur, whose name is so familiar in every corner of the globe where civilization has made itself felt.

Through the labours of Pasteur, and a long list of zealous investigators by whom he has been followed, a large amount of the most interesting and important information has been collected concerning this unseen living world of micro-organisms.

Thus we are not only able to discover their presence and examine their form under the beautiful microscopes which we now have at our command, but we can actually determine the numbers in which they are present at any moment in the air we breathe or in the water we drink. We can also isolate the individual and submit it and its progeny to examination, and so determine the special phenomena to which any particular species is capable of giving rise.

Amongst the vast array of chemical changes or chemical reactions, as we generally call them, which constitute the great science of chemistry, there is probably none which is so well known to the general public, and certainly none which enjoys a more ancient reputation and history than the conversion of sugar into alcohol. There is hardly any race of men so primitive that they have not discovered the method of effecting this change, for to whatever part of the world we turn our attention, we find that in some shape or other a fermented liquid, or in other words an alcoholic liquid, is the favourite beverage of man.

But although the production of this substance has been known from the most remote times, the nature of this change from sugar to alcohol is still one of the obscurest in the whole of chemical science, is still one that the ingenuity and resource of man has been unable to imitate. Now it was the discovery that this important transformation is in every case due to the presence of certain minute forms of life, about one three-thousandth of an inch in diameter, that first caused much attention to be devoted to these micro-organisms of which we now hear so much. It was found some fifty years ago by Cagniard Latour and Schwann that the mysterious substance known to brewers as *yeast* or *barm* was really composed of a vast number of minute oval particles endowed with the powers of growth and multiplication, and, therefore, undoubtedly living.

This substance, which was vulgarly known as yeast, having attracted the attention of scientific men, was in course of time rechristened and received the more imposing, though less generally intelligible, title of *Saccharomyces Cerevisiæ*. Comparatively little further progress was made in our knowledge of these minute forms of life until the alcoholic fermentation was submitted to the most exhaustive investigation by Pasteur, who spent many of the best years of his life in the study of these minute oval particles of yeast.

Pasteur found that these yeast organisms were endowed with the power of decomposing sugar in a perfectly definite manner, and that the products were not only alcohol and carbonic acid, but also smaller proportions of glycerine and succinic acid. But Pasteur further showed that there was not only one kind of yeast, but a number of different races of yeast, differing as much from each other as the different races of men; all of them endowed with this particular power of elaborating alcohol from sugar; but whilst some were especially fitted to do their work at a higher temperature, under a tropical sun so to speak, others were specially adapted to labour in a colder climate, and others again under other specific conditions.

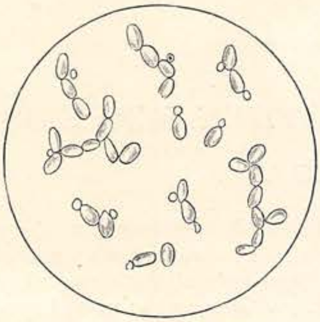

FIG. 1.—"UPPER" YEAST.
(*Saccharomyces Cerevisiæ.*)

Amongst the various races of yeasts distinguished by Pasteur may be mentioned:—

(1). Upper yeast, which is that employed in the brewing of ordinary English beer and in distilleries, characterised by its vigorous action, and by the high temperature of the fermentation to which it gives rise, and by the surface-position which it occupies during the same (see Fig. 1).

(2). Under yeast, which is used in brewing German or Lager beer, and characterised by its slower action, working at lower temperatures, and at the bottom of the fermenting liquid (see Fig. 2).

(3). *Saccharomyces ellipsoideus*, which is always present on the grape skin, and which occasions the vinous fermentation of grape-juice. It is characterised by its slow action at low temperatures, and in a strongly acid liquid (see Fig. 3).

We are naturally led to ask what differences in appearance are exhibited by these several varieties of yeast giving rise to these different types of alcoholic fermentation. It is only by closely examining them with the aid of the best modern microscopes that any points of distinction can be discovered; in fact, so slightly do they deviate in form from one another that it requires an eye well experienced in their study to detect the slight variations which they present. But although the external differences are so slight, brewers are now beginning to realise that the success of their brewing operations depends upon the presence of the suitable and the absence of unsuitable varieties of yeast. Unfortunately important scientific discoveries are slow in bearing fruit in this country, for England appears to be the chosen home of rule-of-thumb and the garden of empiricism, but in countries where practice goes more hand in hand with the advances of science, as much trouble and attention is now given to the cultivation of these various forms of yeast in a state of purity, as is devoted by the most enthusiastic horticulturists to the growth of particular varieties of orchids or roses.

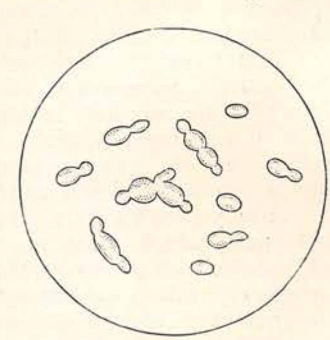

FIG. 2.—"UNDER" YEAST.
(*Saccharomyces Cerevisiæ.*)

Pasteur's researches on the phenomena of brewing led him to discover a number of other micro-organisms, the presence of which are the cause of serious diseases in beer and other fermenting liquids. We are probably all acquainted with the extremely transient excellence of a bottle of claret, which may perhaps be worth ten or twelve shillings when it is first opened, and worth perhaps as many pence twelve hours afterwards, whilst on remaining open for a few days it is as undrinkable as ink. Now this deterioration is chiefly due to the activity of micro-organisms, which in the course of a few hours thus undo the labours which it has taken the yeast, under the guidance of man, years to accomplish. Through the agency of this small organism (see Fig. 4), which rejoices in the long title of *Mycoderma aceti*, the wine prepared according to the most approved methods from the choicest vintages, matured for years in the best cellars in cask and bottle, is converted, in the course of a few hours, into a sour liquid known as vinegar. In appearance this organism differs as entirely from yeast as it does in its functions, being very much smaller and rod-like in shape, generally hanging together in chains, so that it is easily distinguished from the larger and oval-shaped yeast cells.

If we take some pure alcohol and expose it freely to the air, it will in the course of years undergo practically no change ; but bring it into contact, under suitable conditions, with this *mycoderma aceti*, and it rapidly combines with the oxygen of the air, forming acetic acid or vinegar. Now this organism—the *mycoderma aceti*—although much dreaded when it puts in an appearance in places where it is not wanted, *e.g.*, in breweries and in wine vats, is made extensive use of for the actual manufacture of vinegar. Thus the *mycoderma aceti* as well as the *saccharomyces* may be described as domesticated organisms, each of which in their particular way are turned to useful account by man.

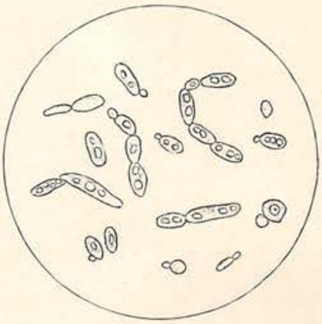

FIG. 3.—WINE YEAST.
(*Saccharomyces ellipsoideus.*)

These two micro-organisms again serve to illustrate a point with which we are very familiar in the higher organisms, viz., that "what is one man's meat is another man's poison." Thus we have already seen that one of the products of the alcoholic fermentation is carbonic acid. Now this substance has practically no prejudicial action on yeast, but entirely arrests the growth and development of the *mycoderma aceti*. It has long been known to the bottlers of wine and beer that it is necessary to have the liquid well charged with carbonic acid, and that if this is not the case it will rapidly become sour; on this account wine and beer have either to be bottled before fermentation is complete, so that carbonic acid may be generated within the bottle, or carbonic acid must be artificially introduced to prevent the growth of the *mycoderma aceti*. It has recently been found that carbonic acid is generally prohibitive to the growth of a great number of different kinds of micro-organisms, and notably to some of the pathogenic or disease-producing forms. Thus I found that Koch's *Comma-bacillus*[1] (see Fig. 5), which is very probably the inducing cause of that excessively fatal zymotic disease known as Asiatic cholera, had its power of growth and development entirely arrested by exposure for several days to an atmosphere of carbonic acid gas. Other organisms again are not so sensitive to this gas as the *comma-bacillus ;* indeed there seems to be no limit to the caprices of these low forms of life as regards food, climate, the air they like to breathe, and other conditions.

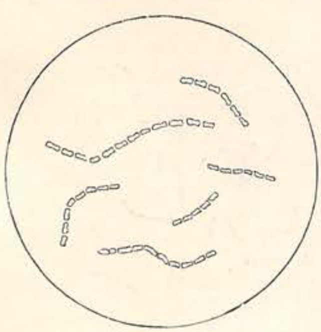

FIG. 4.—VINEGAR ORGANISM.
(*Mycoderma aceti.*)

Quite recently another instance of this selective power of micro-organisms has come under my notice[2] in connection with a certain bacillus capable of exciting an alcoholic fermentation. This bacillus, I found, exhibited a remarkable power of discrimination between two most closely allied sugar-like substances, *mannite* and *dulcite*, which bodies, although of identical chemical composition, possess certain minute points of difference which can however only be detected by the most searching chemical examination. The bacillus in question however appears to appreciate these subtle differences with great readiness, for whilst it produces the alcoholic fermentation in solutions of the *mannite*, it is without action on the closely allied and almost identical *dulcite*.

Perhaps the most remarkable changes which micro-organisms bring about are those in connection with animal and vegetable matter. Under ordinary circumstances these animal and vegetable matters undergo putrefaction and decay, or,

[1] "On the Influence of Carbonic Anhydride and other Gases on the Development of Micro-organisms" (*Proceedings of the Royal Society*, vol. xlv., 1889).
[2] *Proceedings of the Royal Society*, vol. xlvi., 1889, p. 345.

in common parlance, they "go bad." Formerly it was supposed that this "going bad" was an inherent property of such substances. We now know, however, that this putrefaction and decay are entirely dependent upon the presence of certain microbes, and that if the necessary precautions are taken to prevent the access of these organisms, which are abundantly present in all our surroundings, then animal and vegetable matters may be preserved for an indefinite length of time without undergoing any change. This decomposition of vegetable and animal matters is of the very greatest importance in nature, for it is by this means that the fertility of the soil is maintained. Thus it is one of the most elementary facts in practical agriculture that if crops are continuously grown on a piece of land, the latter becomes exhausted, and that some form of manure—generally refuse animal matter—has to be added in order to restore its fertility. Now the exhausted soil is not rendered fertile again by the refuse animal matter itself, but by the products of decomposition, notably ammonia, to which this refuse animal matter gives rise, and in modern agriculture the fertility of the soil is often restored not by the application of farmyard manure (*i.e.*, refuse animal matter), as was formerly the invariable practice, but by the actual addition of ammonia to the land. But this ammonia, which is the primary product of the decomposition of dead animal matter by micro-organisms, is itself capable of undergoing further changes through the action of special organisms. For just as alcohol is in the presence of the *mycoderma aceti* made to combine with the oxygen of the air and is transformed into acetic acid or vinegar, so ammonia, in the presence of certain microbes, which I have recently succeeded in isolating,[1] is made to combine with the oxygen of the air and becomes converted into nitrous and nitric acids.

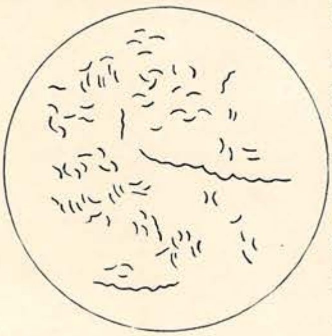

FIG. 5.—KOCH'S "COMMA BACILLUS" OF ASIATIC CHOLERA.

These microbes which transform ammonia into nitrous and nitric acids, and which are generally known as the *nitrifying organisms*, are exceedingly remarkable on account of the extreme simplicity of the food which they require for their nourishment. Thus whilst some organisms are so extremely delicate that like invalids they can only subsist on such highly nutritious substances as blood, milk, beef-jelly, or concentrated broth, these nitrifying organisms can make a living amidst the most barren surroundings. Thus I have found that they will grow abundantly and produce the characteristic transformation of ammonia into nitric acid in a liquid which is practically destitute of organic matter of any kind. Indeed it is only in such starvation-media that these nitrifying organisms succeed in establishing their supremacy, for in more nutritious media they are crowded out by other organisms. Thus in strong liquids, such as sewage, which is rich in food for most micro-organisms, we find no nitrification taking place, but on the contrary an abundance of ammonia. In such a liquid, however, the nitrifying organisms bide their time, waiting until their less discriminating brethren have consumed all the available store of nourishment and are perishing from want; then they step in, make themselves masters of the situation and convert the ammonia into nitric acid in the way already described.

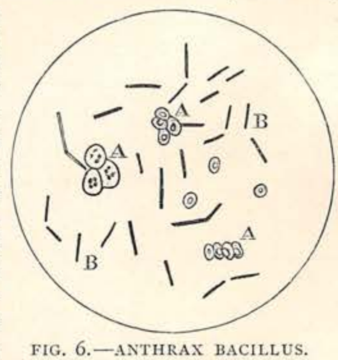

FIG. 6.—ANTHRAX BACILLUS.

Again, one of the most remarkable facts which modern science has brought to light is that many diseases are caused by living organisms. Since the discovery in 1852, that the disease variously known as anthrax, wool-sorter's disease, or splenic fever, is produced by the presence in the blood of the affected man or animal of a particular micro-organism called the *bacillus anthracis* (see Fig. 6[2]), year by year one disease after another has been conclusively demonstrated to be the result of similar

[1] "The Nitrifying Process and its Specific Ferment," by Percy F. Frankland and Grace C. Frankland. (*Phil. Trans. Royal Society*, 1890.)

[2] In this figure A represents the blood-corpuscles, B the anthrax bacilli.

causes. Thus at the present time we have indisputable evidence that in addition to anthrax, erysipelas (see Fig. 7), tuberculosis (of which one of the commonest forms is pulmonary consumption) (see Fig. 8), chicken cholera, glanders, and swine fever, are brought about by the presence of micro-organisms; whilst in the case of many other diseases the proof is all but complete.

Now the question naturally arises, how the presence of these minute living organisms in the system of an animal causes such serious disturbance to health. That the disturbance is the result of the mere mechanical action of these micro-organisms appeared from the first to be inadmissible, more especially as the number of the organisms present is sometimes comparatively small and quite insufficient to account for the extent of the lesion. On the other hand, it was early suggested that the real cause of the mischief to the system was in all probability due to some chemical substance produced by the microbes, possessing strongly poisonous properties. Numerous facts have been found to support this theory, and in recent years attempts have been made to isolate these microbial poisons, and although we are not yet in possession of the actual poisons causing any of the typical zymotic diseases, still a number of intensely toxic substances produced by micro-organisms have been separated and obtained in a state of purity.

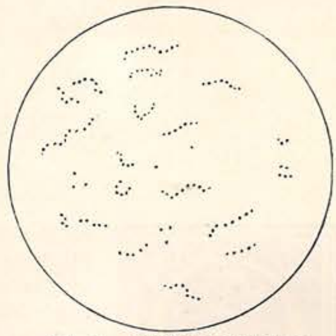

FIG. 7.—STREPTOCOCCUS OF ERYSIPELAS.

Intimately connected with these poisons elaborated by microbes is the subject of protective inoculation. The most familiar form of this protective inoculation is ordinary vaccination, in which a comparatively small number of the microbes are introduced into the system there to multiply abundantly and to effect some change, possibly to remove some necessary food-material, so that the system will no longer favour the growth of the same organism if it subsequently gain access. The system thus becomes protected by having supported a crop of organisms and is incapable of maintaining a second, immunity from the particular disease being thus secured for a longer or shorter period of time in the future. It has, however, been found that protection may be secured in the case of some diseases without inoculating the living organism at all, but by introducing only a certain quantity of its products on successive occasions and in increasing quantities. In this case the protection obviously depends upon accustoming the system to the particular poison, just as persons may by practice become accustomed to taking doses of arsenic or opium which would prove immediately fatal to ordinary people. Considerations of this kind have led Pasteur to devise the systems of preventive inoculation for anthrax, for chicken cholera, and more recently for the terrible hydrophobia, which is doubtless a disease produced by microbes, although as yet undiscovered.

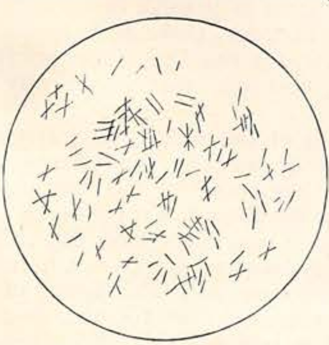

FIG. 8.—BACILLUS OF TUBERCULOSIS.

Even the preceding very cursory survey of these micro-organisms is sufficient to show with what important issues the study of these creatures is surrounded, for the significance of their action is equally striking whether we regard them from a purely theoretical point of view, or whether we consider them in their relationship to the industries, to agriculture, or to public health. Thus of theoretical interest is the important light which they throw upon many chemical and physiological reactions. In many industrial processes they are the indispensable agents, subject to the guidance and regulation of man. In agriculture they bring about the most important changes, and serve to maintain the equilibrium between the animal and vegetable kingdoms on the earth. Finally, their relationship to health and disease is of such an intimate character, that an increasing knowledge of the properties of these organisms has already led to a material diminution in the death-rate, through improved sanitary conditions and the prevention of zymotic disease.