SCIENCE
IN
SUGAR PRODUCTION

T. H. P. HERIOT

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AN INTRODUCTION TO THE METHODS OF CHEMICAL CONTROL.

BY

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Preface.

Although the sugar industry is abundantly provided with technical literature, no previous attempt has been made to bring the methods of science within easy reach of the practical sugar maker.

This was undertaken in a series of articles on "Simple Methods of Chemical Control," which appeared in the International Sugar Journal, and are here brought together in a revised form.

T. H. P. HERIOT.

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PART I.

INTRODUCTORY.

CHAPTER I.

WHAT IS MEANT BY CHEMICAL CONTROL.

SUGAR being a product of vegetable life, the sugar factory may be regarded as a machine for converting dissolved sugar into crystals; or for packing the produce of many acres of land into the smallest possible compass. As it is impossible to get more work out of a machine than is put into it, so it is impossible to get more sugar out of the factory than enters it in the form of raw material. Indeed, it is impossible to get as much, notwithstanding all improvement in sugar machinery and the accumulated experience of centuries. Some sugar is invariably lost; that is, not converted into crystals, the causes being various and sometimes obscure.

Whereas some losses appear to be unavoidable, even when skilled labour and the best machinery are at hand, there are others due to the continued use of inferior machinery or processes, and to ignorance or carelessness on the part of employees, so that the total loss in many sugar factories is a serious obstacle to economic production.

Before greater economy is possible it is obviously desirable to know the actual extent of the losses incurred by applying the methods of the accountant in the factory. It is thus ascertained, for example, that the output of crystallized produce constitutes 90% of the total sugar entering the factory as raw material. On comparing this result with previous records, or, better still, with the results obtained in the best equipped factories, it is seen whether the work is good, bad, or indifferent. Similarly, a knowledge of the composition of the various by-products leads to greater vigilance in each department of the factory, and even suggests where improved appliances might be adopted with advantage. In a word, progress is impossible until we know precisely where we stand and in what direction to move.

The kind of information required must refer to quantities of sugar contained in the various materials treated in the factory, and as such quantities can only be ascertained by means of chemical analysis, the work of collecting the necessary data is termed *chemical control.*

Chemical analysis tells us the *percentage composition* of the samples analysed, and, in addition to this, we require to know how much factory produce these samples represent. Evidently, then, chemical control is based on weights and measurements in the factory.

The weight of cane may be regarded as the principal factor controlling operations in the field as well as in the factory. The planter thus learns what yields he obtains from different soils ; how these yields are affected by the application of various manures or by different methods of cultivation ; and, last but not least, what varieties of canes yield the heaviest crops. The sugar-maker, on the other hand, should regard the weight of cane (or, strictly speaking, the sugar represented by that weight) as something to be hereafter accounted for. But, as is too frequently the case, what is most desirable is often neglected or done indifferently, for unless this duty is entrusted to thoroughly competent and well-paid weighers, the result will only mislead the practical man who relies on "figures." A degree of accuracy which satisfies the cane farmer does not necessarily pass muster with the chemist, who always has to reckon with the accumulation of small errors.

The accurate weight of cane being the starting point, a complete chemical control should show at a glance the total weight of sugar entering the factory in the form of canes, the percentage recovered as crystallized produce of various grades, the percentage remaining unextracted in the molasses and other by-products, and, finally, the losses occurring at different stages of manufacture. In addition to this routine work, chemical control is required in connection with the distillery, in testing new procesess or machinery, and in reducing incidental working expenses by testing the quality of the fuel and stores supplied.

Regarding the manufacture, the reader may ask whether chemical control ensures a higher recovery of crystallized sugar from a given weight of cane, or merely indicates the admitted imperfections of our present methods of working ? To this we reply that without chemical control we should never have ascertained how imperfect our methods are in themselves, nor how imperfectly they are employed. It is not sufficient for the sugar producer to know that his results are as good, or even better than his neighbour's.

Are they as good as the means at his disposal permit ? Can these means be improved, and, if so, in what direction ? Here the facts to be ascertained are beyond his keenest powers of observation, and " practical experience " completely fails him. Differences which are inappreciable to his unaided senses must be magnified and measured by suitable instruments, and approximate calculations, such as have hitherto sufficed, must give place to accurate statistics.

Absolute accuracy is of course impossible, but that it is an ideal to be aimed at may now be shown. Chemical control is not merely a matter of testing, but also of directing the factory operations by aid of the knowledge gained in the laboratory. But, being unable to handle such quantities as are dealt with in the factory, the chemist makes his tests by means of samples, and all his measurements and weights are of a lilliputian order. Hence, though his laboratory errors may appear insignificant enough, they become painfully evident when magnified to the scale of operations in the factory—the only scale, be it observed, on which they have any *practical* value. If errors in testing are unavoidable (and no chemist is infallible), another source of error has to be guarded against. Unless the *sample* truly represents the *bulk*, the chemist's efforts will be misdirected and his conclusions quite unreliable. Accuracy in sampling is therefore as essential as accuracy in testing.

That scientific knowledge is not yet recognised as the basis of everyday practice may be due to the small scale on which manufacturing operations are generally conducted, necessitating under-paid and inefficient staffs ; a state of things which can only be remedied by the gradual amalgamation of estates and the erection of large central factories.

In the meantime, those who continue working on the old lines should be preparing themselves for the future by taking an intelligent interest in what has been held of little practical account by their predecessors. Rule-of-thumb practices must be criticised from a theoretical point of view, and new ideas tested ; in short, a scientific habit of mind should be cultivated. Scientific terms and formulæ may be unattractive and frequently obscure, but the general principles are within the reach of all. In the sense that one need not be an engineer in order to understand the commercial value of a machine, one need not be a chemist in order to judge of his utility.

It is from this standpoint that we propose to assist the practical man to perform a few simple tests himself, believing that when he is once convinced that science is not " all theory," he will be ready to welcome the trained chemist as a useful co-operator.

With practice, anyone can become proficient in working the polariscope, and but little more is necessary to realize the advantages of chemical control. It is the object of this volume to give such instruction and practical hints as will enable the planter, engineer, or factory manager, to do for themselves that which, in the absence of a chemist, has generally been left undone. Should this attempt succeed, it might appear that the sugar industry could get along very well without the chemist's aid, but there is other work for him to do as will now be shown.

CHAPTER II.

THE ROLE OF THE CHEMIST IN THE SUGAR INDUSTRY.

Commencing with the factory, the chemist may turn his attention to:—

1.—CHEMICAL CONTROL OF THE MANUFACTURE.

This may consist of a few daily tests, such as will be hereafter described, but a more complete control is always desirable. In this direction alone there is plenty to occupy the chemist's time during the crop season. In a beet sugar factory three or more chemists are generally engaged in this work.

2.—TESTING NEW PROCESSES OR MACHINERY.

In addition to the daily control, additional tests are necessary whenever the methods of manufacture are modified and it is desired to ascertain the advantages so gained. Similarly, when new processes are installed, the chemist's control must be such as will furnish the fullest information as to the advantages of the new system over the old, for it is mainly on the chemist's evidence that new processes are judged.

3.—DEVISING NEW OR IMPROVED METHODS OF MANUFACTURE.

The chemist, himself, may possess inventive talent, and thus be able to suggest improvements. This, at any rate, will be his aim and should be encouraged by his employers.

4.—TESTING STORES USED IN THE FACTORY.

Besides the chemicals used in the manufacture, various materials are bought in large quantities, sometimes without questioning their quality or suitability for purposes to which they may be put. Adulteration may easily escape the eye of the store-keeper, but is easily detected in the laboratory.

5.—THE CONTROL OF LABOUR IN THE FACTORY.

As the estate-owner naturally looks for the highest possible returns for the salaries paid out, the following question frequently arises :—Would not the chemist be more useful in the factory than in the laboratory ? As this generally means higher remuneration, the chemist is not unwilling to play the rôle of factory manager ; but as he cannot be in two places at the same moment, some of his analytical work has to be abandoned unless he is provided with a competent assistant.

It cannot be denied that some chemists make very successful factory managers, but so far from their ability to control labour being the result of a scientific training, it has no connection with it whatever. The chemist having been trained to use his own hands rather than to supervise the work of others, his " market value " consists in his ability as a skilled *worker*, and this should surely determine what kind of work he is best fitted for. Presumably the sugar producer thinks that as the chemist knows all about the juice he should be in charge of the factory operations. This argument would be sound enough but for the fact that the chemist's knowledge has to be gained day by day, because the materials treated in the factory are ever changing. To sum up on this head, the chemist's duty is to acquire knowledge in the laboratory in order that he may advise in the factory. "Nigger-driving" requires no technical skill, and may be better performed by others.

So far as factory operations are concerned, the rôle of the chemist is somewhat restricted. He can do nothing towards increasing *the yield of sugar per acre*, but has to make the most of what the planter brings to the mill. Economy in the factory is desirable, but is certainly not the only step needed to place the sugar industry on a sound scientific footing.

Economy in the field is no less desirable, and here, again, the first step is to obtain more exact knowledge of the materials treated. The sugar cane resembles other crops in requiring certain mineral substances or " plant-foods," and as these must come from the soil, the latter may be regarded as the raw material upon which the planter operates. To adapt the soil to the requirements of any crop it is necessary to know what mineral " foods " are required by that crop, and, further, what stores of these "foods" are present in the soil. How, otherwise, can the planter know what manures should be applied or what mechanical treatment of the soil will be most effective ? Unfortunately, many planters think that an ounce of practice is worth a ton of theory, and not understanding the methods of the chemist, they regard his analytical results with suspicion and prejudice. To show that the chemist is no less practical than the planter, let us now compare their respective methods of solving a familiar problem—What kind of manure should be applied to a certain soil, of which neither the planter nor the chemist have had previous experience.

The planter will set to work tentatively, trying various manures in succession and noting the effects of each. This experimental method is perfectly sound if properly followed up, but, with *no theory* to guide the planter, many experiments may be necessary before the best kind of manure is thus ascertained. This is essentially the "method of experience," whether carried out by one planter (as here supposed), or by generations of planters, each of which makes some contribution to the stock of experience bequeathed to him.

But knowledge even when founded on experience is not necessarily reliable, since experience may be based on appearances instead of on facts. For example, daily experience convinced our forefathers that the sun revolved round our earth ; they were deceived by *appearances*. To-day, all educated people admit that it is our earth which moves —not because appearances have since changed—but solely because a *wider experience*, based on more exact knowledge, has proved the older view to be wrong.

So, in matters relating to the sugar cane, it must not be forgotten that the practical planter is largely dependent on *appearances* as a guide to practice and as a basis of his experience. This being admitted, no one will deny that there is still ample scope for scientific enquiry in connection with the agricultural side of the sugar industry, and it remains to indicate in what directions the chemist might assist the practical planter.

6.—THE ANALYSIS OF SOILS, FERTILIZERS, ETC.

We have now to describe the method adopted by the chemist in solving the planter's problem.

A few ounces of the pulverised soil are shaken up with dilute acid, the strength of which has been previously adjusted to imitate the root-sap of the living plant. From a known weight of soil the chemist thus extracts certain minute quantities of lime, phosphoric acid, potash, etc., which are separately weighed, and approximately represent the store of plant-foods in the soil, which, on account of their solubility, are immediately available to the growing crop. By analysing the sugar cane he also learns what constituents of the soil are removed by the crop, and in what relative quantities, and, finally, on comparing their ratios with those yielded by the soil-extract, he learns what essential plant-food is lacking in the soil and requires to be added in the form of manure. Actual experiment in the field will then decide whether this element should be applied in any particular form in preference to others. The delicate balance of the chemist is less liable to err than the planter's judgment; nor must it be forgotten that *the same soil* may require different treatment according to the period it has been under cultivation.

When, as is frequently the case, the analysis of a soil gives no indication as to what manures should be applied, it is necessary to appeal to the experimental method already described. The planter, therefore, must not look for a prompt answer to every question he may put to the chemist.

Finally, as regards the quality of the manures supplied, the planter is dependent on the chemist for knowing whether he receives good value for his money.

7.—EXPERIMENTS IN THE FIELD.

Whether the planter wishes to try a new manure or a new variety of cane he must experiment, and the value of the conclusions eventually drawn will depend solely on how the experiment is carried out. In claiming that the chemist should be responsible for all experiments, we have in view the special difficulties which such work presents, and the need for more constant supervision than the planter's various duties permit. To carry out an experiment in the field the chemist must, of course, be familiar with the routine work of the plantation, although this does not concern him so much as what lies *outside* that routine; namely, the special conditions which constitute the experiment, and the precautions to be observed.

(1) The kind of soil selected for the purpose will depend on the nature of the experiment; it should be of uniform depth and fairly constant in composition.

(2) As a large area of soil is seldom quite uniform, the experiment must be so arranged that should such differences exist, they would not influence the result.

(3) "Tops" for planting up the experimental field must be individually examined and only sound ones used.

(4) If manures are under trial, the quantities it is proposed to apply must be carefully weighed and properly dis-

tributed over the cane-rows, by adding a certain measureful to each "hole."

(5) When once the experimental conditions have been arranged, all further operations must be carried out as in the ordinary routine.

(6) The experimental crops must be separately harvested and weighed. As the quantity and quality of the juice is the all important thing, an experimental *field* really necessitates an experimental *mill.*

Having indicated how a chemist may be usefully employed on a sugar estate, it now remains to be seen what the sugar producer might do without the chemist's assistance.

CHAPTER III.

CHEMICAL CONTROL WITHOUT A CHEMIST.

A complete control, as outlined in Chapter I, is a laborious undertaking, but, bearing in mind that one test, accurately made, gives definite information, we suggest that a *partial* control, capable of detecting *avoidable losses*, would be a step in the right direction. Let us illustrate this. The cane mill being admittedly defective as a method of extraction, it is of less consequence to know how much sugar is thus unavoidably lost than to know when *unnecessary* loss occurs owing to defective adjustment, irregular feeding, etc. A simple method of gauging the amount of water left in the megass may here serve to indicate the efficiency of the extraction without resorting to more refined analytical methods required for the estimation of the sucrose.

Our second step will be to note the volume, density, and saccharine richness of the juice, in order to ascertain the "indicated sugar" entering the factory, the highest possible percentage of which must be extracted in the form of saleable crystals.

Tempering or liming being a chemical treatment of the juice, is easily controlled by simple chemical tests in the hand of the clarifier "boss," but the mud discharged from the filter bags or presses will require occasional analysis.

The multiple evaporator has fortunately minimised avoidable losses during evaporation of the juice to syrup. Inversion (*i.e.*, the transformation of crystallizable sucrose into uncrystallizable glucose) invariably occurs when neutral or acid saccharine liquids are continuously heated, but with properly tempered juice it is never considerable, and, from our present point of view, may be regarded as unavoidable.

The subsequent concentration of syrup to masse-cuite is something more than a mere process of evaporation, being, indeed, the only manufacturing operation demanding highly skilled labour if avoidable losses are to be minimised. The merest tyro can boil a pan and produce crystals *of a sort*, but it takes the best part of a lifetime to learn to work a pan with the highest possible efficiency. The pan-boiler is responsible for loss of sugar due to over-heating (inversion), insufficient concentration before striking out, and loss of first product which occurs when the grain is too small, irregular in size, or mixed with false grain. Here, if anywhere, chemical control may be employed with the greatest practical advantage, and if each strike of masse-cuite could be separately weighed and cured, careless work would be easily detected, and the necessary steps taken to prevent its repetition. Unfortunately this desirable precaution is rarely practicable, and the improved methods of handling masse-cuite now coming into use only add to the difficulty of weighing, or accurately measuring, large quantities of this material. For the partial control it will be more satisfactory to determine the yield of sugar from each strike of masse-cuite on an experimental scale.

The working of the centrifugals will be controlled by "polarizing" the cured sugar, and suitable tests will show when the maximum quantity has been recovered by re-boiling the molasses.

As the small factory can rarely dispense with artificial fuel, in the form of coal, wood or bamboo, our partial control will conclude with some observations regarding the quality of the fuel.

As the first and all important thing is to obtain accurate weights and measurements in the factory, the following notes are here introduced :—

1. WEIGHT OF CANES.—Accurate weighings being rarely possible, except where transport is by rail and with a scale capable of weighing several trucks simultaneously, these conditions will have to be assumed in what follows. The precautions to be observed being, however, of general applicability, may serve as a guide to the manager of a small factory, where canes have to be weighed in single cartloads. The types of weighing machines requiring no special description, we proceed at once to consider how errors may be detected.

(*a*) *Clerical errors* are the most frequent, and may include errors in reading off the weight from the machine in addition to those of recording the same. Both may be eliminated by using the Patent Recording Steelyard made by Messrs. Avery (*b*) *Errors in the tare.*—The trucks should be weighed singly before the commencement of the crop season after being put in thorough repair. The weights may be painted on the sides of each truck, but it is better to merely number the trucks and to record the corresponding tares on a card fixed over the cane-weigher's desk; the number of each truck forming one load should be recorded opposite the gross weight, so that the net weight of cane may be subsequently checked.

(*c*) *Errors of the scale.*—These are comparatively rare, but may be caused by over-loading or by sudden strains. The scale should be erected so as to allow free access to the reducing levers (supporting the platform) so that any defect in their action may be detected by an occasional examination. A scale should be tested to its full loading capacity at least once a year, and this is most conveniently carried out by weighing a train of trucks, loaded with as many bags of sugar as will approximately represent the weight of a load of cane. The true balance of the empty scale being first secured by careful adjustment, the tare of each empty truck is noted. The sugar must be bagged off on a tested sugar scale with every precaution to ensure accuracy, and the requisite number of bags loaded into each truck. If the indicated weight does not agree with the known weight (of the bagged sugar plus the tare weights of the trucks), the difference is the error of the scale when fully loaded. By detaching one truck at a time and weighing the remainder, there will be obtained a series of observed errors (probably diminishing as the load on the scale is reduced) which must be individually recorded. The correction to be applied to subsequent weighings of cane will, in that case, depend on the number of trucks forming each weighed load.

(*d*) *Errors due to fraud* are not uncommon where canes are purchased from the farmer. The possibility of bribing a native cane-weigher to falsify his weights should never be lost sight of; there are also many ingenious methods of making a load weigh more than it should. Except where farmers' canes are weighed in carts at a loading station, and then loaded into trucks which are weighed at the factory yard, the weights will always remain open to criticism. The quantity of trash, roots, etc., which accidentally finds its way to the scale must be approximately known when a chemical control is to be based on the weight and saccharine richness of the canes ground, and it is generally sufficient to supervise the unloading of one truck every day so that the débris may be collected and weighed.

(*e*) *Errors due to evaporation* of water from the cane occasionally occur when some mishap in the factory stops the mill, leaving a quantity of cane in the yard. If such a stoppage can be foreseen, a few trucks may be weighed separately, and re-weighed as soon as milling operations recommence; the loss in weight being then calculated on the total weight of canes in the yard. But in other cases it is very difficult to apply a proper correction, as the loss by evaporation mainly depends on temporary atmospheric conditions.

2. MEASUREMENT OF THE JUICE.—The direct weighing of juice being at present an unsolved problem, the alternative method of measurement is the one usually adopted. But the juice, as it flows from the mill-bed, is covered by a thick layer of foam, so that accurate measurement of the true volume is very difficult. When heated nearly to its boiling point, all air is driven off, and the liquor presents a clean surface, but its true volume is now exaggerated owing to expansion by heat, for which a correction must be applied. Again, in order to measure a continuous output of juice, more than one measuring vessel must be available. To convert a battery of liming tanks into measuring vessels, provision must be made for filling the tanks to a certain level, say a few inches from the open top. A good way of doing this is to rivet a short arm or bracket to the top of each tank, so that the arm projects horizontally over the liquor; the free end of the arm may then either be bent vertically (downwards), and the bent portion tapered to a point, or, preferably, an inverted cone is attached to the extremity of the arm or bracket. In either case, the point indicates the exact height to which the liquor is allowed to rise, the juice-cock being closed as soon as the surface of the juice touches the point. If too much be added, this is easily detected by the point being slightly immersed. Such indicators are easily made at the forge, and should be securely fixed to the tanks in a position clearly visible to the workmen in charge. The next step is to carefully measure the internal dimensions of the tanks as regards length and breadth; the required depth being the distance between the points and the bottom of the tank. (Note.—It is convenient, though not essential, that each tank should hold a round number of gallons, or other measures, and that the exact level to which they are filled should allow for expansion by heating, and thus eliminate corrections.)

Such measurements presuppose that the sides of the tanks are not bulged or otherwise out of shape. In such cases, or where the capacity cannot be easily calculated from the dimensions, it must be directly ascertained by filling the tank with water to the required level, and running the water into a vessel of known capacity, which, if smaller, is repeatedly filled.

The small quantity of milk of lime, added to each clarifier, does not cause any appreciable error, but it is important that the mixing of the tempered juice should cease before the tank is filled, in order to avoid agitating the surface of the juice when the level is finally adjusted.

The accuracy of such measurements depends entirely on the men in charge of the work, but as errors in opposite directions tend to neutralize each other, the plan is sufficiently exact. For a complete chemical control, the adjustment of the level should be effected automatically by means of an overflow from each tank into the next, or into a gutter from which the surplus juice gravitates back to the juice pump. The men in charge have then merely to fill the tanks until juice commences to overflow.

3. Weight of Sugar Cured.—Even this every-day practice calls for a few remarks. The scale should be kept scrupulously clean, carefully handled, and moved as little as possible. The empty scale should be balanced daily before bagging off commences, and a loaded test made once a week by means of standard weights. One-tenth the weight of ten bags serves as an accurate tare to be added to the net weight of sugar per bag. If the bags be filled whilst on the scale, and never lifted on to it after being partly filled, the " life " of the scale may be doubled. By attention to such details the customary surplus or " over-weight " may be reduced without risking complaints.

4. Weight of Fuel.—A coal-scale is a sound investment for every small factory where such fuel is necessary. If used intelligently, it will show how much coal is required per day by each furnace.

PART II.

The Practical Methods of the Laboratory.

CHAPTER IV.

Fitting up the Laboratory.

As the mechanic requires a working bench, and a place to keep his tools, so the chemist requires accommodation for his apparatus and a few conveniences to facilitate his work. A suitable room may generally be found in the manager's house or the overseer's quarters; or a portion of the general office may be partitioned off to serve as a laboratory. The main essentials are that the room should be well lighted, free from vibration, and used for no other purpose.

The furniture should include :—

Two tables measuring about				3ft. 6in. × 2ft. 6in.
One	,,	,,	,,	2ft. 6in. × 1ft. 6in.
Two stools or chairs.				

A **Sink** may be made out of the small table just referred to, the exact dimensions of same being immaterial. Procure a piece of sheet lead large enough to overlap the top of the table by four inches on every side. Flatten this out upon the table and turn down the overlapping portions against the edges of the table-top; the corners being neatly folded without cutting. This having been done, the lead is lifted off the table, turned over, and replaced, when it will have the appearance of a shallow tray. The sides of this tray are next enclosed by a wooden frame constructed of four pieces of 1in. board about 4in. wide, screwed to the edges of the table and projecting 3 inches above it, but not quite as high as the sides of the lead tray. As the tray is slightly larger than the table (*i.e.*, by twice the thickness of the lead sheet) distance-pieces of the same lead must be nailed round the edges of the table-top before the side pieces are screwed on.

The lead tray being temporarily removed, a 1¼ inch hole is bored through the centre of the table-top, and around this hole a slight depression is cut to allow the soldered joint of the waste-pipe to be countersunk. The tray is now placed in position, flattened down upon the table, and the portion projecting above the wooden framework turned over and nailed to the latter. The lead is gently hammered into the central depression, and a neat hole made in the lead to correspond with that in the table. A piece of compo-piping, to just fit the hole, is pushed up from beneath the table until it projects ½ inch above the tray ; this end being then expanded and hammered out to form a flange which can be soldered to the sheet lead of the tray. The complete sink will then have the appearance shown in Fig. 1 (but the sides of the sink will be vertical).

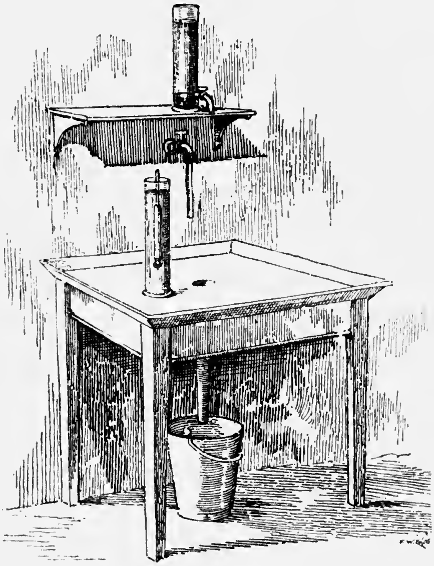

FIG. 1.

The convenience of connecting the sink with a water supply, and of extending the waste pipe to the nearest drain will be obvious, although it is possible to make-shift with a bucket of water (standing on the sink), and an empty bucket placed below to receive the waste. As shown in the illustration, the sink also serves as a working bench, and should therefore be placed in a well lighted position.

DRAINING RACKS. Time and trouble can be saved by allowing apparatus to drain dry after being washed. For this purpose, two shelves should be fixed to the wall, one above the other, so as to project over the sink. The lower shelf (about 8in. above the sink) is pierced with a row of ¾ in. holes about 1½ in. apart ; these holes being large enough to admit the neck of an inverted measure flask. The second shelf (about 12in. above the lower one, and projecting beyond it) is provided with a row of slots, 1¾in. deep (from the front), 1½in. wide, and with spaces of 1½in. between each slot. These admit an inverted hydrometer cylinder, the foot of which, being wider than the slot, is supported by the shelf.

All glass ware should be washed at the sink immediately after use and not be left over for a "cleaning up" day, when everything is dirty. If, after being washed and left to dry on the draining rack, the glass-ware still looks dirty, this will be due to the impurity of the water supply, and it will be advisable to have a vessel of rain-water handy, into which the washed apparatus can be dipped before being left to drain. The measure flasks, in which juice, etc., has been treated with basic acetate of lead, can be cleaned by rinsing with dilute muriatic acid (one part of acid to one of water). As this acid can be used over and over again, it may be kept in an open phial or cylinder into which the acid rinsings are emptied back. The flasks are then washed free from acid, rinsed with rain-water, and left to drain. A spare bucket, kept underneath the sink, serves as a receptacle for all rubbish.

One secret of tidiness is to stow away in a cupboard all appliances other than those in daily use, dust being excluded by plugging measure flasks, pipettes, etc., with cotton-wool, and by covering cylinders with paper caps.

By utilising the sink as a working bench for taking densities and for operations likely to make a mess, the "balance table" may be reserved for the more delicate operations.

SHELVES, ETC.—One or two narrow shelves are required for bottles; a small writing bench in one of the windows, with a shelf at the side for books; and a cupboard for storing apparatus when not in use.

CHAPTER V.

WEIGHING AND MEASURING.

Chemical tests may be either qualitative or quantitative. Qualitative tests show whether this or that substance is present in an unknown material; quantitative tests show the relative proportions of the constituents or the *percentage composition*. The qualitative composition of the sugar cane has long been known, but as the fibre, water, sugar, etc. occur in very variable proportions, the chemist is constantly ascertaining the percentage composition of sugar canes, of the juice expressed from them, and of the various products into which the juice is worked up. As his analyses are made on small samples, we may be prepared to find that his weights and measures are of an entirely different order to those used in the factory, and therefore require some description here.

THE METRIC SYSTEM dates from 1801, and although employed for ordinary purposes by three hundred million people in twenty countries, this system is still unfamiliar in Great Britain and her Colonies.

The METRE, or unit of length, was supposed to represent one ten-millionth part of the distance from the pole to the equator, and corresponds to 39·371 inches. Although subsequent measurements of the meridian have proved that the metre is somewhat less than its founders had supposed, its actual length was not corrected, and to-day it is an arbitrary standard represented by a metal rod kept in Paris.

From this unit, others are derived as follows. The LITRE is the capacity of a cubical vessel, each side of which measures exactly a tenth of a metre. The GRAM is the weight of the thousandth part of a litre of distilled water, measured at 4°C.

Larger and smaller measures of length, volume, and weight are obtained by multiplying or dividing the above units by 10, 100, 1000, as shown below:—

Length.	Metre.	Volume.	Litre.	Weight.	Gram.
Millimetre	= $\frac{1}{1000}$	Millilitre	= $\frac{1}{1000}$	Milligram	= $\frac{1}{1000}$
Centimetre	= $\frac{1}{100}$	Centilitre	= $\frac{1}{100}$	Centigram	= $\frac{1}{100}$
Decimetre	.. $\frac{1}{10}$	Decilitre	= $\frac{1}{10}$	Decigram	= $\frac{1}{10}$
Metre	= 1	Litre	.. 1	Gram	= 1
Decametre	= 10	Decalitre	= 10	Decagram	= 10
Hectometre	= 100	Hectolitre	= 100	Hectogram	= 100
Kilometre	= 1000	Kilolitre	= 1000	Kilogram	= 1000

Instead of employing different words (*i.e.*, ounces, pounds, quarters, etc.,) to express multiples of one kind, it will be seen that metrical measures are distinguished by prefixes, which are the same for all similar multiples and can be committed to memory in a few minutes.

The direct relation between length, volume, and weight, may now be illustrated as follows:—

1 Cubic Metre = 1 Kilolitre = 1000 Kilograms.
1 Cubic Decimetre = 1 Litre = 1 Kilogram.
1 Cubic Centimetre = 1 Millilitre = 1 Gram.

When this unified system is contrasted with that jumble of independent standards so dear to the British nation, the great simplicity and practical advantages of the metrical system will be readily seen. It has long been universally adopted for scientific work, and laboratory measurements are mainly concerned with grams and cubic centimetres.

A ton of material can be weighed in the factory to within, say, one pound. Let the former weight be represented in the laboratory by a sample weighing one decagram (less than a half-ounce), then every pound weight in the factory will be represented by $\frac{1}{2240}$th part of a decagram, say $4\frac{1}{2}$ milligrams ($\frac{1}{10000}$th part of an ounce.)

Should such minute weights appear to have no practical meaning, we submit an illustration from the mining industry. A gold-bearing ore, if favourably situated, can be worked at a profit though it contains only half an ounce of gold to the ton. How is the richness of such an ore ascertained ? Samples are sent to the assayer's laboratory and submitted to certain smelting and refining operations by which the gold may be separated without loss. But the assayer's "ton" is less than 30 grams, and the above proportion of gold would be represented by half a milligram. He must therefore employ a balance capable of detecting the tenth part of one milligram (or the ten thousandth part of one gram). Here, then, is an instance of an important commercial undertaking being set on foot and its operations controlled by weighing the "infinitely little."

The Chemical Balance.

This instrument is dismantled for packing, and the various parts will be found in the drawer of the case. They should be carefully unwrapped and exposed to view whilst the following instructions are read through. No attempt to fit the parts together should be made until these instructions have been thoroughly mastered.

The Balance "Case" permanently protects the instrument from dust and also shields it from draughts when in use. The windows and woodwork may require polishing with a soft cloth. The only fixture in the case is the central brass pillar with horizontal supports for the "beam." The pillar is hollow and encloses a moveable rod on the top of which is fixed a horizontal plate of agate. This plate will be seen to rise a short distance when the milled screw (in front of the case) is turned to the right, but returns to its lower position when the milled screw is reversed.

The "Beam" will be easily recognisable among the parts taken from the drawer. When in position, the sharp edge of the central agate prism rests upon the horizontal agate plate referred to above, forming a fulcrum upon which the beam can swing with a minimum of friction. At either end of the beam are smaller agate prisms having their edges directed upwards; these will eventually support two small agate plates attached to the hooks from which the pans are suspended. On examining the two sides of the beam, that which should face the operator is marked with two small dots at the end opposite *his left*, and with one dot at the end opposite *his right*. The pans, hooks, and stirrups are marked with one or two dots, according as they belong to the right or the left side of the balance.

The Pointer. In order that the slightest motion of the beam may be rendered visible, a long pointer is fixed at its centre in the following manner. Unscrew the brass knob from the centre of the beam, and place the flat end of the pointer in its place, so that the pointer is on the marked side (or front) of the beam; the two pins on the pointer fitting into the holes provided for them in the beam. The knob is now replaced and screwed home upon the pointer. Wipe the beam clean and place it upon the supports in the balance case.

THE HOOKS, from which the pans are suspended, are connected to small-grooved agate plates, which may now be placed upon their supports at either end of the beam; the hook marked with two dots going to the left hand side. The pivotted bar on each stirrup is set at right-angles to the fixed bar, to receive their respective pans, and then the stirrups are suspended from their proper hooks.

THE PENDULUM serves to indicate when the balance is properly levelled. Its position behind the central pillar is clearly shown in Fig. 2.

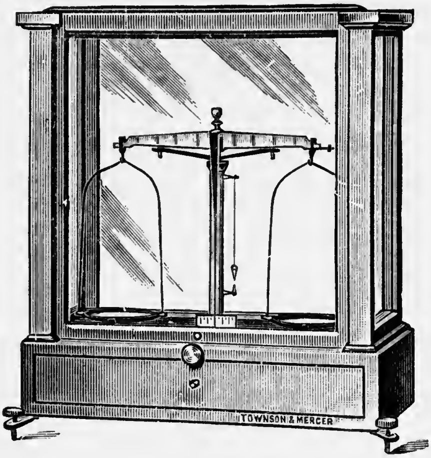

FIG. 2.

ADJUSTING AND TESTING THE BALANCE. One of the two large tables should occupy a central position in the laboratory and on this the balance is placed exactly opposite a window. The first adjustment consists in levelling the instrument by means of the two screws at the foot of the case; the adjustment being complete when the the pendulum-bob is exactly over the point fixed to the central pillar.

When not in use, the milled screw of the balance is always turned to the left, thus lowering the vertical rod [which supports the central agate plate. In this position, the beam rests entirely upon the rigid supports, the central agate plate being lowered out of contact with the central agate knife-edge on the beam. In the same manner, the two extremities of the supports (not shown in *Fig.* 2), are adapted to lift the grooved agate plates clear of the small agate knife-edges at either extremity of the beam. The "bearings" of the beam and pans are thus held out of gear until a weighing has to be made, so that the addition of weights to either of the pans has no effect whatever. But on slowly turning the milled screw to the right, the central agate plate is first raised into contact with the central knife-edge, and then lifts the beam clear of its supports, the grooved plates being simultaneously raised upon their knife-edges so that the pans hang freely. If, now, the pointer remains opposite the centre (zero) of the scale, the balance is probably correct. Should the pointer move away from the centre of the scale, count the divisions it moves over, first on one side and then on the other of the zero line. If these agree, the balance is correct, but the beam may be allowed to swing once or twice to make quite sure. To bring the oscillating beam to rest, watch the movements of the pointer, and, when it approaches the zero line, gently reverse the milled screw.

(NOTE.—Unless this precaution is observed the agate knife-edges receive a sudden jar which may permanently affect the delicacy of the instrument).

Should the foregoing test fail to cause the beam to swing, it may be necessary to turn the milled screw with a slight jerk ; but the motion thus imparted to the beam should not be sufficient to carry the pointer beyond the last division of the scale. A few minutes' practice will render this operation easy.

If the pointer covers, say, seven divisions to the right and only two to the left, it is obvious that the left side of the balance is heavier than the right. Assuming that all the parts are clean, and that the pans and hooks are attached to their proper ends (as indicated by the marks referred to above), the balance must be adjusted by means of the small nut on the threaded pin which projects from the right hand extremity of the beam. On the above supposition, this nut must be moved away from the centre of the beam (in order to increase its apparent weight by increasing the leverage it exerts upon the central fulcrum). This is effected by a very slight turn of the nut in the required direction. The milled screw is again turned and another observation made. With a little patience this adjustment is soon completed ; the pointer swinging an equal number of divisions on either side of the zero of the scale.

Fig. 3 represents a set of gram weights. The 100, 50, 20, 10, 5, 2, and 1 gram weights are of brass ; then come the tenths (decigrams) made of aluminium foil and marked ·5, ·2, ·2, ·1 ; then the hundredths (centigrams) marked ·05, ·02, ·02, ·01 ; and, lastly, the thousandths (milligrams) made of aluminium wire and distinguished only by their shape, ·005 having five sides, ·002 two sides, and ·001 being a short straight piece. These weights must never be fingered, but are lifted from the box and returned to it by means of the forceps supplied for the purpose. The box must be kept closed when not in use. If a weight accidentally falls, search should be immediately made for it, as it would be completely ruined if trodden upon.

The delicacy of the balance may be tested by placing the ·001 (milligram) weight on one of the empty pans, and turning the milled screw. Unless the beam is caused to swing, the pointer will probably be deflected one division from the zero where it will remain steady. But if the beam oscillates, the deflection of the pointer becomes more conspicuous; it may, for example, move three divisions to one side and five divisions to the other. A more severe test is made as follows:—On one pan place the 100 gram weight, and on the other the 50, 20, 10, 10, 5, 2, and three 1 gram weights, so that each pan carries its maximum load of 100 grams. The motion of the beam will now be somewhat slower, but the pointer should still travel equal distances on either side of the zero of the scale, if the weights are accurate. If there is any inequality, this must be accurately noted. Bring the beam to rest, add the milligram weight to one of the pans, and repeat the test. The pointer will now move, say, four divisions on one side and five divisions on the other, and these indications should be reversed if the milligram be transferred to the other pan. Having thus proved that the balance will do what the makers claim for it, a complete record of these tests may be preserved for future reference.

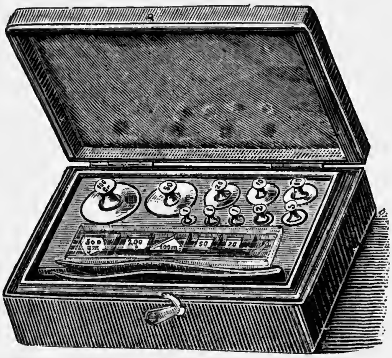

FIG. 3.

USING THE BALANCE. Always use the right hand pan for the weights and the other pan for the object to be weighed. The milled screw being turned by the left hand, the right hand is free to manipulate the weights by means of the forceps. When weighing an object, a rough guess is first made as to the largest weight to be placed on the pan, the other weights are then "tried" in regular order, from the highest downwards. In making such "trials" the milled screw should only be turned sufficiently to cause the pointer to move a short distance from the zero of the scale. If turned as far as it will go, the pointer merely moves beyond the limits of the scale, and gives no better indication; time is lost, and the agate surfaces are submitted to unnecessary friction. The beam should only be fully raised when the weights on both pans are nearly equal, requiring the addition or removal of the milligram weights. After some experience in the use of the balance, the relative excess or deficiency of the "trial" weight may be gauged from the rapidity with which the beam moves away from the zero of the scale when the milled screw is turned. To avoid mistakes in recording the weights, these should be first ascertained by reference to the empty cavities in the box, and the result checked by reference to the weights themselves when restoring them to their places. Accuracy and speed can only be acquired by practice, and with this end in view, a number of coins should be separately weighed and then two or more reweighed together, the results being checked against each other.

These instructions may fitly conclude with a few maxims:—

1. Never use the balance in a hurry.

2. Open and close the front of the case without shaking the instrument, and always close the case and weight-box after use. Do not open or close the case when the beam of the balance is raised.

3. Watch the pointer when turning the milled screw, and never reverse the screw unless the pointer is near the zero line.

4. Make the final observation with the case closed.

5. Always bring the beam to rest before adding or removing anything from the pans.

6. Never be satisfied with a weight that is "nearly right," but aim at the highest possible accuracy. When this has been acquired, there will be time enough to decide whether extreme accuracy may sometimes be neglected.

7. Every object placed on the balance pans must be scrupulously clean and *dry*.

8. Whenever the balance appears to require adjustment, suspicion should fall upon the pans, and these should be removed and polished with the leather. The adjustment nut should only be interfered with when all other precautions fail.

THE MEASURE FLASK.

Measurement of volume is a much more simple matter than measurement of weight, the instrument maker being responsible for the graduations on the flasks and other vessels used for this purpose.

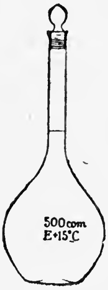

FIG. 4.

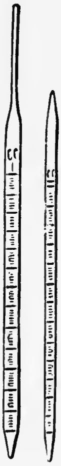

FIG. 5.

FIG. 6.

The flask illustrated in Fig. 4 holds exactly 500 cubic centimetres (c.c.) or half a litre, when filled to the mark on the neck. As the addition of a single drop in excess causes a slight but visible alteration of level, such a flask is capable of measuring to within $\frac{1}{5000}$ part of its total capacity.

Actual trial will show that the level of the liquid, when viewed sideways, does not appear as a straight line but as a curve, called a meniscus (this curvature being caused by the capillary attraction of glass for liquids). Consequently, the volume is accurately adjusted when the lowest point of this curve appears to touch the horizontal line marked on the flask. (see Fig. 6).

Occasionally it is required to dilute a known volume of liquid by one-tenth, for which purpose flasks are graduated with two marks, thus, 50 and 55, 100 and 110, 200 and 220.

Small volumes must be measured more accurately than large volumes if the same *relative accuracy* is to be maintained throughout.

The narrow tubes, or pipettes, shown in Fig. 5, are graduated in separate cubic centimetres, and in tenths of one c.c., and are manipulated as follows :—Holding the instrument near its upper end (between the second finger and thumb of the right hand), immerse the pointed end in the liquid of which a measured quantity is required. Applying the mouth to the top of the pipette, the liquid is drawn up by suction until the level rises above the zero mark ; the mouth is then quickly replaced by the tip of the forefinger (of the right hand), which closes the top of the tube. The filled pipette can now be raised without any liquid escaping from it, and is brought into a perpendicular position with the zero mark level with the eye. The pressure of the finger on the tube being slightly relaxed, liquid begins to slowly drip from the lower end of the pipette, while the level of the liquid in the upper part sinks towards the zero mark. As soon as the lowest point of the meniscus appears to touch the zero line, the pressure of the forefinger is renewed, and the downward motion of the meniscus arrested. The drop (or fraction of a drop) adhering to the exterior of the pipette is removed (by touching it with a finger of the left hand), and that remaining inside measures exactly 10 c.c. This volume may now be transferred to another vessel by merely removing the forefinger from the pipette which then empties itself, the last drop being blown out. If 8 instead of 10 c.c. are required, the top of the pipette is reclosed by the forefinger as soon as the descending meniscus reaches the 8 c.c. mark. These manipulations are performed in a few seconds after a little practice.

In filling the measure flask, the lip or spout of the vessel containing the liquid should touch the neck of the flask, causing the liquid to flow down the interior surface of the flask without splashing. With a steady hand, the pouring may be continued exactly up to the mark, but we recommend the following plan. The flask (filled nearly to the mark) is held vertically with the mark level with the eye. Sufficient liquid is then added from a short pipette to bring the level in the flask up to the mark. The pipette need not in this case contain a measured quantity of liquid and merely serves to regulate the addition to the flask.

These measurements should be practiced with water, which gives a clearly defined meniscus.

CHAPTER VI.

PREPARING A SOLUTION FOR ANALYSIS.

The first step in analysing a solid substance, such as a sample of raw sugar, is to prepare a solution of same which will contain a known weight in a known volume. This will serve to illustrate the combined use of the balance and measure flask and also to introduce certain other appliances.

Loose materials, like sugar crystals, must never be placed directly on the pan of the balance, as it would then be necessary to clean the pan each time the balance was used, not to mention the difficulty of removing the weighed portion of sugar from the pan *without any loss*. Such materials are always weighed into a vessel which has been previously counterpoised, and the German silver basin shown in Fig. 7 possesses the advantage that the sugar, molasses, etc., after being weighed, can be dissolved therein by the addition of water.

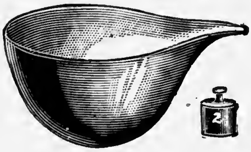

FIG. 7.

The basin is provided with a" counterpoise weight," loaded with shot. The top of the weight unscrews, so that if the tare of the empty basin be not exact, one or more shot may be added or removed, the finer adjustment being made by small fragments of tin-foil, wire, or even paper. This having been done, the tare of the basin is not likely to appreciably alter by wear, and only needs to be checked occasionally.

To prepare a 20% Solution, the 20 gram weight is added to the counterpoise weight (on the right hand pan), and the sugar added to the basin by means of a spoon or a bone spatula. After each addition, the balance is "tried" by slightly turning the milled screw, and the quantity in the basin increased or diminished until the pointer swings equally on both sides of the zero. In the case of sugar crystals, the final adjustment may be made with a few grains which have been crushed to a powder, so that very small quantities can be added at a time.

Removing the basin from the balance, the chemist should now be seated at the table. 40 c.c. of rain water are measured off in one of the larger graduated cylinders, poured into the basin, and the contents stirred with a glass rod. When the sugar appears to have dissolved, the resulting syrup is decanted into a 100-110 c.c. measure flask in the manner shown in Fig. 8; the rod being held so that only its extremity touches the neck of the flask.

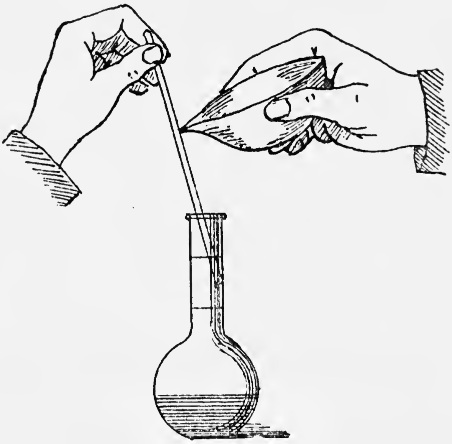

FIG. 8.

Replacing the rod in the basin, 30 c.c. more water are added, and this will completely dissolve any trace of sugar remaining. After this has been similarly decanted, 10 c.c. of water are slowly poured down the rod while the latter is moved round the upper part of the basin, so as to wash down any drops of syrup from the sides of the basin and rod, and this wash water added to the flask as before. A final rinsing with another 10 c.c. of water will completely remove the last trace of sugar from the basin, The contents of the flask are then diluted exactly to the 100 c.c. mark, by adding water from a pipette as already explained. The object of measuring the water into the basin is merely to avoid a too liberal use of water for dissolving, which might nearly fill the flask before the basin and rod had been rinsed.

To mix the heavier syrup with the subsequent rinsings, the flask must be closed and inverted several times. The use of a cork may, however, be obviated by closing the mouth of the flask with the thumb while the neck of the flask is gripped between the fingers and the palm of the hand.

Such a solution may serve as a starting point for many tests, because the 20 grams of sugar dissolved therein may be accurately subdivided by withdrawing measured volumes of this solution Thus, 10 c.c. will represent two grams of the original sample; 50 c.c. 10 grams, and so on.

The following experiment is instructive as illustrating how the chemist is able to deal with weights too minute to be detected by the most sensitive balance. Starting with the above 20% solution, measure off exactly 10 c.c. in the pipette, and transfer this volume to a second 100 c.c. flask, fill up the latter exactly to the 100 c.c. mark with water, and mix as before. The result is a 2% solution, from which, by repeating the operation (using a clean pipette and a third flask) a 0·2% solution is obtained. By mere repetition of these simple measurements the dilution may be carried on until the last flask contains the merest trace of sugar, the weight of which *is still known*, although probably represented by the fifth or sixth place of decimals. The same result would be reached in one-third of the time if 1 c.c. of the original solution had been diluted to 1,000 c.c. (1 litre) and so on. We thus see that infinitesimal quantities can be measured without substituting "theory" for "common sense" at any step of the process.

Now, the sugar crystals with which we started will contain certain quantities of moisture, glucose, and mineral matter (or ash), each of which would have to be measured if a complete analysis were desired. Usually, however, it suffices to ascertain the percentage of actual sugar (sucrose) by means of the polariscope, and as this method can only be employed with perfectly transparent and nearly colourless solutions, some additional preparation will be necessary before our 20% solution is fit for the optical test.

Many liquids can be rendered clear by simple filtration through a special kind of paper (filter paper), but this is rarely possible in the case of impure sugar solutions. The difficulty is overcome by treating such liquids with a solution of basic acetate of lead;* a treatment which closely resembles the tempering of juice on a large scale, but is even more effective.

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* NOTE.—One of the small bottles, with flat stopper, should be filled with this reagent and labelled "Poison"; the Winchester quart bottles being stowed away in the cupboard.

Fill a 50-55 c.c. flask to the lower mark with the 20% sugar solution, add 2 c.c. of lead solution from a pipette, dilute with water to the 55 c.c. mark, and mix. The result is a milky fluid, which, on merely standing for a short time, separates into two portions,—a precipitate which slowly settles in the flask, and a transparent and almost colourless liquid.

The soluble impurities present in the original sample have here combined with the acetate of lead to form insoluble compounds, which, taking the form of a precipitate, envelop and carry down the fine insoluble particles which rendered the original solution cloudy. Sucrose being unaffected by the acetate of lead, the saccharine richness of the original solution has only been modified by the dilution, and this being exactly one-tenth, a very simple correction can be applied. This method of clarification *by dilution* will be found convenient when we come to analyse the juice, but when preparing a solution of sugar crystals it is more convenient to add the lead acetate before adjusting the volume of the sugar solution in the flask by proceeding as follows :—

Weigh out another 20 grams of sugar, dissolve and decant the solution as before, but add 2 c.c. of lead acetate to the flask after the first or second decantation. Rinse the basin twice, dilute to the 100 c.c. mark, and mix. When this is filtered, the clarified liquid will be a 20% solution of the original sample, requiring no subsequent correction. Filtration is effected as follows :—

Fold one of the circular discs of filter paper in half, and re-fold so that the double portions come together. Repeat this re-folding twice again and the result will be as in Fig. 9. Opening out the paper, the "fluted" filter, shown in Fig. 10 is obtained, which fits into the glass funnel,† as in Fig. 11.

Holding the funnel in the left hand, pour the contents of the measure flask upon the filter, and after allowing the first few drops (which are cloudy) to escape, place the funnel upon a clean (and dry) cylinder as illustrated in Fig. 11. After covering the top of the funnel with a disc of ground glass to prevent evaporation, the apparatus can be left until sufficient filtrate has collected for optical examination, to be hereafter described.

A clear distinction should finally be drawn between percentage *by volume* and percentage *by weight*. If 20 grams of sugar are dissolved

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†NOTE.—The stems of the funnels are shortened by making a file-mark round the stem, firmly grasping the latter on each side of the mark, and then drawing the hands apart with a jerk, at same time exerting a slight bending strain.

in 80 grams (=80 c.c.) of water, the solution weighs 20+80=100 grams, and is therefore a 20% solution of sugar *by weight.* But the percentage *by volume* will be more than 20 because the 80 c.c. of water employed are not increased to 100 c.c. by the addition of the sugar, but to somewhat less than 90 c.c. Consequently, if 90 volumes contain 20 grams, 100 volumes contain 22 grams, so that the same solution may contain 22% by volume and 20% by weight.

FIG. 9.

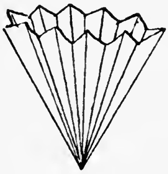

FIG. 10.

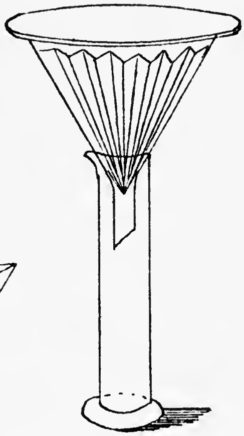

FIG. 11.

Conversely, the 20% solution by volume (as prepared above) would have weighed more than 100 grams, say 105 to 106 grams, and therefore must have contained less than 20% by weight.

This distinction being once clear, it is merely a matter of convenience whether percentages are expressed by volume or by weight; the former being preferable in the case of liquids which are measured, and the latter in the case of solids which are weighed. Actual examples will appear in subsequent chapters.

CHAPTER VII.

THE DENSITY TEST.

By density, or specific gravity, is meant the weight of a substance as compared with that of an equal volume of something else selected as a standard, and, in order that the densities of different substances may be compared one with another, it is essential that they should refer to one and the same standard. Distilled water being particularly suitable for this purpose, has been universally adopted.

Density may therefore be defined as the ratio which the weight of a given volume of a solid or liquid bears to the weight of the same volume of distilled water taken as unity, the compared volumes being measured at a definite temperature. The latter qualification is an essential one, because, at different temperatures, the same weight of any substance occupies different volumes; or conversely, equal volumes of the same substance vary in weight.

A knowledge of the specific gravity of liquids finds frequent application in the arts and industries, either for calculating weights from volumes and *vice versa*, or for measuring the strengths of liquids as regards the quantity of solid matters held in solution, or the extent of dilution of one liquid by another. Whereas, in the first case, specific gravity serves merely as a measure of relative weight, in the second case *the cause* of the variations in relative weight serves as an approximate measure of composition.

As an example of the former, we find that a certain volume of cane juice weighs seven-hundredths more than the same volume of distilled water, both liquids being measured at 62°F. The ratio of the weights of these equal volumes being, then, 107 : 100, the specific gravity of the juice becomes 1·07 when the weight of water is taken as unity. And since a gallon of distilled water, at 62°F., weighs exactly 10 lbs., we learn that a gallon of such juice must weigh 10·7 lbs.

On the other hand, we find by actual experiment that solutions containing various known percentages of pure sugar differ considerably in density; and, referring to the tabulated results of such experiments, that a solution of specific gravity 1·070 should contain 17% by weight of pure sugar. But the specific gravity of an impure solution, such as cane juice, being due to the relative specific gravities of its constituents, serves only as an approximate indication of saccharine richness.

Of the various methods of finding the density of a liquid, the hydrometer test is by far the simplest, and therefore deserves exclusive attention. Although some form of this little instrument is to be found in every sugar factory, few of those who use it daily have taken the trouble to learn the principle on which it acts, and the conditions under which its indications can be relied upon.

As in the case of all floating bodies, the hydrometer displaces a volume of liquid equal to its own weight, but, unlike the displacement of a ship, which varies with the weight of cargo, the displacement of the hydrometer varies only with the density of the liquid in which it floats. To render the instrument sensitive to slight differences of density, the upper part, or stem, is given the form of a narrow tube, the total displacement of which is small as compared with that of the submerged bulk of the instrument. The variable displacement of the hydrometer is indicated by the length of stem submerged ; which length increases (for equal variations in density) in proportion to the narrowness of the stem. The weight of the hydrometer being constant, it is obvious that the volume of liquid displaced by its submerged portion varies inversely as the density of the liquid, but is always equal in weight to the hydrometer. The principle involved is, therefore, that of comparing the volumes of equal weights of the liquid tested and of water. If this is once clearly understood, the reader will be saved much perplexity arising from the various methods of graduating the hydrometer scale, which we must now briefly refer to.

From the sugar maker's point of view, the hydrometer should indicate either—(*a*) true specific gravities (relative weights), from which data the weights of juice and syrup can be calculated from their volumes. Or (*b*) the percentage of dissolved solid matter, which is the cause of variations in specific gravity. These two methods of graduating the hydrometer are equally rational and practical. The confusion referred to above is largely due to a third method of graduation adopted in the Beaumé hydrometer, the degrees of which are arbitrary numbers yielding no intelligible information until reference is made to a table of figures. Not only is this scale graduated on an irrational basis, but, being generally designed to indicate a large range of densities, it also lacks sensitiveness, owing to the relatively large diameter of the stem. When employed in the sugar factory, all the possible densities of cane juice fall within about an eighth part of the scale, on which a quarter of one degree occupies not more than a twentieth part of an inch. Strange to relate, this most unpractical hydrometer is still preferred by practical men for reasons best known to themselves. As a " workman's test " it may have its uses, but as a laboratory instrument it can happily be dispensed with.

Of the two rational methods of graduating the saccharometer, or " sugar-hydrometer," a scale indicating percentages of dissolved solids will be found more useful than one indicating specific gravities, and as both graduations cannot very well be combined on a single scale, the corresponding specific gravities are usually found by reference to a table.

The Brix or Balling Saccharometer is graduated to indicate percentages of sucrose when floated in solutions of pure sugar. Such solutions, therefore, take the place of distilled water as the standard adopted. As impurities exert their influence on the density of any liquid, the degrees Brix of cane and beet juices are taken to represent the percentage of sugar plus impurities ; in other words, the percentage of total solids in solution. This percentage, deducted from 100, represents the percentage of water. When the exact estimation of the sugar is made by the optical test, the Brix scale enables us to arrive at the quantity of sugar per 100 parts of dissolved solids, otherwise known as the " quotient of purity."

It should be noted, however, that since the specific gravity of sucrose is higher than that of the impurities which accompany it, the degrees Brix only indicate *apparent solids*, and these are in excess of the *true solids* (determined by the more round-about method of evaporating a weighed quantity of juice and drying the residue to constant weight). We here meet with an instance where great accuracy is not essential so long as the information yielded is strictly comparative. Whereas measurements of the *quantity* of sucrose in the juice call for every possible precaution in order to check the yields obtained in the factory, the *purity* of the juice, based on the apparent solids, is only a rough guide as to what that yield should be. Provided, then, that slight differences in the purity of juices can be detected, it is not of serious consequence whether the results are expressed in absolute or relative terms.

Having selected the Brix scale as the most suitable, there still remains the question—at what temperature shall the scale be graduated and used? Most hydrometers, including the Brix, are graduated at European temperatures and require a heavy correction when employed in the tropics, for reasons already stated. Now such corrections may be perfectly reliable, and, in some cases, highly convenient, but unfortunately they do not tend to simplify matters. We therefore prefer a Brix instrument graduated at a mean tropical temperature of 84°F. and specially made to order. Within the limits of 82°–86°F. no correction is then necessary, but the readings of the scale must be increased by one-tenth for every 3 degrees above 84°F., or decreased to the same extent for every 3 degrees below 84°F., as here shown:—

Degrees F.	Reading.	Corrections.	Corrected Brix.
78	18·2	—·2	=18·0
81	18·1	—·1	=18·0
82–86	18·0	Nil	=18·0
87	17·9	+·1	=18·0
90	17·8	+·2	=18·0

The mere substitution of one kind of saccharometer for another would be of doubtful advantage unless accompanied by greater exactness and attention to details in testing; hence the necessity of a few hints on making the test.

When not in use, the saccharometer is conveniently kept in a cylinder filled with water to such a level that only the uppermost inch of the stem remains uncovered. This end serves for holding the instrument, which should be handled as little as possible.

Having completely filled another cylinder with the juice to be tested, and removed every trace of air bubbles (by blowing off the surface juice), the saccharometer is raised from the water-cylinder, the *stem only* wiped dry with a clean cloth, and the instrument lowered into the juice until part of the stem is immersed, being held centrally in the cylinder. On now releasing the stem, the saccharometer sinks only a short distance before finding its proper level, leaving the exposed part of the stem *dry*. This is important because a *wet stem* increases the active weight of the saccharometer and thus falsifies the reading.

We have already referred to the meniscus of liquids when dealing with measure flasks, and the same phenomenon has to be taken into account when reading off the density from the Brix scale. Figure

12 gives a sectional view of the upper part of the cylinder, showing the meniscus produced where the liquid surface comes in contact with the sides of the cylinder and of the Brix stem. As the latter is graduated with reference to the normal level of the liquid, which we saw (Chapter V.) to be the lowest point of the meniscus, the correct reading is here 17·4 and not 17·2 as measured at the highest point.

Although the above precautions may appear to be superfluous refinements, they are necessitated by the obvious defects in this simple method of testing densities. Where extreme accuracy is required, as in many scientific investigations, even the most perfect hydrometer would be considered insufficiently accurate.

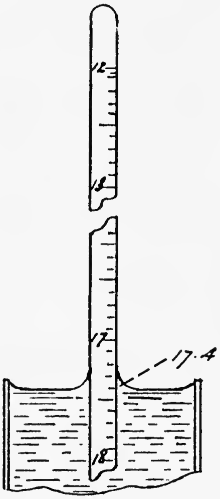

FIG. 12.

In the Table on the opposite page, the reader will find the weights per gallon of juice corresponding to each degree Brix at 84°F., and we must now explain how these figures were obtained.

As specific gravity expresses the ratio between the weight of a given volume of a liquid and that of an equal volume of distilled water, at a definite temperature, we have here to apply this principle to the measurements adopted in the factory. The imperial gallon is defined as that volume of distilled water which, when measured at 62°F., weighs exactly 10 pounds. If, therefore, we know the specific gravity (or relative weight) of juice at 84°F. as compared with water at 62°F., we have only to multiply the specific gravity figure by ten in order to find the weight in pounds of a gallon of

TABLE I.

Brix. at 84° F.	Weight of Juice.		Brix. at 84° F.	Weight of Juice.		Brix. at 84° F.	Weight of Juice.	
	Pounds per gallon.	Gallons per ton.		Pounds per gallon.	Gallons per ton.		Pounds per gallon.	Gallons per ton.
12·0	10·446	214·4	15·0	10·575	211·8	18·0	10·707	209·2
12·1	10·450	214·3	15·1	10·579	211·7	18·1	10·711	209·2
12·2	10·454	214·3	15·2	10·583	211·7	18·2	10·715	209·1
12·3	10·459	214·2	15·3	10·588	211·6	18·3	10·720	209·0
12·4	10·463	214·1	15·4	10·592	211·5	18·4	10·724	208·9
12·5	10·467	214·0	15·5	10·596	211·4	18·5	10·728	208·8
12·6	10·472	213·9	15·6	10·601	211·3	18·6	10·733	208·7
12·7	10·476	213·8	15·7	10·605	211·2	18·7	10·737	208·6
12·8	10·480	213·7	15·8	10·609	211·1	18·8	10·742	208·5
12·9	10·485	213·6	15·9	10·614	211·0	18·9	10·746	208·5
13·0	10·489	213·5	16·0	10·619	210·9	19·0	10·751	208·4
13·1	10·493	213·5	16·1	10·623	210·9	19·1	10·755	208·3
13·2	10·497	213·4	16·2	10·682	210·8	19·2	10·759	208·2
13·3	10·502	213·3	16·3	10·632	210·7	19·3	10·764	208·1
13·4	10·506	213·2	16·4	10·636	210·6	19·4	10·768	208·0
13·5	10·510	213·1	16·5	10·641	210·5	19·5	10·772	207·9
13·6	10·515	213·0	16·6	10·645	210·4	19·6	10·777	207·9
13·7	10·519	212·9	16·7	10·649	210·4	19·7	10·782	207·8
13·8	10·523	212·9	16·8	10·654	210·3	19·8	10·786	207·7
13·9	10·528	212·8	16·9	10·658	210·2	19·9	10·791	207·6
14·0	10·532	212·7	17·0	10·663	210·1	20·0	10·795	207·5
14·1	10·536	212·6	17·1	10·667	210·0	20·1	10·799	207·4
14·2	10·540	212·5	17·2	10·672	209·9	20·2	10·804	207·3
14·3	10·545	212·4	17·3	10·676	209·8	20·3	10·808	207·3
14·4	10·549	212·3	17·4	10·680	209·7	20·4	10·813	207·2
14·5	10·553	212·2	17·5	10·685	209·6	20·5	10·817	207·1
14·6	10·558	212·1	17·6	10·689	209·6	20·6	10·822	207·0
14·7	10·562	212·0	17·7	10·693	209·5	20·7	10·826	206·9
14·8	10·566	212·0	17·8	10·698	209·4	20·8	10·831	206·8
14·9	10·571	211·9	17·9	10·702	209·3	20·9	10·835	206·8

juice measured at 84°F.; the reason being that the figure representing specific gravity refers to water as unity, whereas that representing a gallon of juice refers to ten units (pounds) of water.

Tables for converting degrees Brix into specific gravities are published in various text books on sugar, but as such tables are based on the relative weights of juice and distilled water when both liquids are measured at 63·5°F., they are inapplicable at the above mentioned temperature.

The figures in the accompanying table were therefore determined by actual experiment as follows:—

A Brix saccharometer was ascertained to be accurate by floating it in solutions containing various known percentages of pure sucrose at a temperature of 84°F. After each reading of the scale, a small quantity of each solution was transferred to a bottle (so constructed that it could always be filled to precisely the same level). The bottle plus sugar solution was then weighed, and the tare of the empty bottle deducted. In this manner the weights of equal volumes of sugar solutions at 84°F., varying in density from 12 to 20 Brix, were noted down. The bottle was finally filled with distilled water at 62°F. and the weight of the water similarly noted.

The latter weight being then adopted as unity, the specific gravities of the sugar solutions were found by dividing their weights by that of the same volume of distilled water. These values, multiplied by ten, gave the weights (in pounds) of one gallon of each solution corresponding in density to the different numbers on the Brix scale.

The same result is reached more directly if we regard the weighing bottle as a miniature gallon measure. Then, the weight of distilled water at 62°F., which exactly filled it, would represent ten pounds, and the weights of the sugar solutions at 84°F. proportionally more than ten pounds.

The results thus obtained were finally corrected for slight experimental errors until they showed graduated differences in the weighings corresponding to the whole numbers on the Brix scale. The intermediate weights, corresponding to tenths of degrees Brix, could then be filled in by calculation. These weights per gallon appear in the second column of the Table, and, if the decimal points be (mentally) moved one place to the left, the corresponding specific gravities are seen at a glance.

A second method of expressing the weight of juice is given in the third column of the Table, namely the number of gallons of juice which would collectively weigh one ton. The use of these factors will be more fully explained in a subsequent chapter.

CHAPTER VIII.

THE OPTICAL TEST.

We have now to explain how the more valuable constituent, the crystallizable sugar (or sucrose) may be quantitatively distinguished from the impurities which accompany it. This is essentially a problem of analysis which can be solved in various ways, but the simplicity of the " optical test " renders the polariscope available to the practical sugar maker, be he a chemist or not.

The Brix Saccharometer is but an approximate guide, and may be compared to the mariner's compass. For finding the exact position, the polariscope has the same importance in the factory as has the sextant on board ship.

The polariscope further resembles the sextant in being a somewhat complicated instrument, although easily manipulated after a little practice. Consequently, the reader who desires to know how cane juice is analysed will not rest satisfied with being told to place his eye at one end of an instrument, and to turn a screw until he obtains a certain optical effect. He would naturally want to know something about the instrument itself, and concerning the why and wherefore of the instructions given him. Believing that such knowledge may prove of interest, we propose to devote some space to theoretical considerations, commencing with :—

THE NATURE OF LIGHT.

Attempts to explain how the eye becomes affected by distant objects have led to several theories regarding the nature of light itself. The ancients imagined that vision was due to particles escaping from the eye and passing in straight lines towards the object seen ; this idea being superseded, or rather, modified, by supposing the particles to be emitted by the source of light, the eye being a passive receiver. This latter view was supported by the weighty authority of Sir Isaac Newton, who conceived a luminous object as a sender of light, and the eye as a receiver, the transaction between the sender and receiver being of the same nature as a ball thrown and caught.

This theory explained many of the facts then known, but finally received its death-blow at the hands of *the wave theory*.

Since Newton's time we have become familiar with greatly improved methods of communication between distant persons. Instead of sending a letter through the intervening space, we now frequently resort to the telephone and telegraph. Here also, we find a sender and a receiver of the message, but that which is sent and received is no longer a material object, but an electrical disturbance communicated to a wire stretched between the two parties. Although the exact nature of an electrical disturbance is still unknown, we have abundant evidence of the transference of mechanical disturbances which will help us to understand the wave theory of light.

A stone thrown into a pond momentarily depresses a portion of the liquid surface. In returning to its normal level, the depressed liquid acquires sufficient momentum to carry it a certain distance above that level, so that an up and down motion continues for some time. Although only a small area of water was struck by the stone, the disturbance is gradually communicated to the most distant parts of the pond in the form of a rippling circle. This first ripple is closely followed by numerous others, each of which is caused by the alternating (or vibratory) motion of the water at the point struck. A floating object on the surface of the pond rises and falls above and below a fixed point, thus indicating the motion of the water particles. Hence we learn that an up and down motion can be transmitted horizontally.

Passing from this simple case of transmission of motion along a surface, we must now briefly refer to another. A distant bell affects a certain part of the ear; its action must therefore be direct or indirect. Direct action at a distance being inconceivable, we are driven to the only alternative, namely, that there is something between the bell and the ear which acts as a carrier or transmitter of sound, and experiment has proved this supposition to be correct. An electric bell and battery were placed under the receiver of an air pump, and, in proportion as the air was removed from around the vibrating bell, the audible effect became less, and finally ceased. The hammer continued to strike the bell as before, but the vibrations of the latter were isolated from the experimenter's ear by removing the transmitting agent. By the careful study of the vibratory motions of sounding bodies, the structure of the hearing organ, and the physical properties of the atmosphere and of other transmitting media, the wave-theory of sound is now established beyond all possibility of disproof. The nature of sound-waves does not here concern us, but it is important to note that they travel in every conceivable direction from the centre of disturbance, and, in this respect they exactly resemble the waves of light.

When distant objects affect the eye, instead of the ear, a similar mechanical explanation is sought for, and there are very good reasons for believing that both light and heat are due to vibratory motion of the particles composing the luminous and the heated body ; although the infinitesimal dimensions of such vibrations would require a transmitting medium possessing very remarkable properties. Rather than abandon a theory, for which no better could be substituted, scientists had to resort to an imaginary medium, permeating all space and all forms of matter, and thus eluding human effort to isolate and examine it.

This medium, called the "luminiferous ether," may be purely imaginary and the wave theory of light erroneous, but so long as the latter is not disproved by any observed facts it can be accepted as a guide to further enquiry, and has, indeed, already led to discoveries of great practical value.

To explain the optical principles of the polariscope by the aid of this theory, we shall have to employ very crude illustrations and also to rely somewhat on the imaginative powers of our readers. Let us, however, start with the familiar fact *that light travels in straight lines*, as is seen when a beam of sunshine enters a darkened room through a small aperture. The floating atmospheric dust, lying in the direct path of the beam, becomes brilliantly illuminated, and it is easy to imagine the beam so reduced in size as to become a straight line without breadth.

To fix this idea, let us return to our former illustration of the telegraph wire, and imagine a large central office, with wires radiating in straight lines to every point of the compass ; increasing the number of wires indefinitely until the intervening space between the central and distant offices becomes completely filled with wires. Regarded collectively, these wires would represent a vast mass of metal, and, in order to explain how such a metallic mass acts as a transmitting medium, we might proceed by showing what takes place along any single wire. If the central office merely sends out messages to the distant offices, and the latter communicate with each other over local wires, the above analogy will be complete. For the central office substitute a source of light; for the receiving offices—objects illuminated by that light; for the intervening metallic media—the luminiferous ether; for the single wires—rays of direct light; and for the single local wires—rays of reflected light. As a telegraphic message can be transmitted by a wire hundreds of miles in length with the same facility as when the wire is but a few inches long, so, in the case of light, distance is quite immaterial from the point of view of transmission, however much the intensity of the light may be diminished.

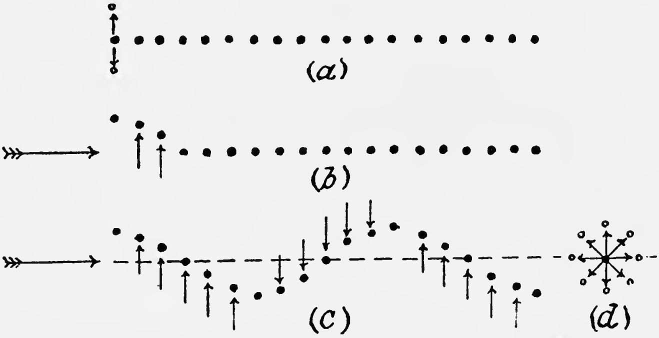

FIG. 13.

At (*a*) in Fig. 13, an imaginary line is drawn through space, and a few of the many particles of the ether, lying in that line, are represented by dots. No luminous body being present, the particles are all at rest, but are capable of a slight "to and fro" motion, like an individual in a crowd; such motion being brought about either by direct contact with vibrating solid matter (a source of light), or by contact with other ether particles which have thus been set in motion. In other words, the vibratory motion of the *source* of light can be imparted to the surrounding particles of ether, these in turn, handing on the motion to the more distant particles of ether, and so on.

Consequently, each particle of ether represented at (*a*) is capable of moving out of line, but in doing so it meets with resistance in every direction from other particles than those actually shown. Its motion being thereby constantly reversed, the particle vibrates like a pendulum between two extreme positions as shown by the two outline dots in (*a*).

Let us suppose that a source of light appears to the left of our line of ether particles, then the left-hand particle of ether will be set in motion by direct contact with the vibrating solid matter, assuming one of its extreme positions as at (*b*). But one particle cannot move out of line without disturbing that which lies next to it, so that a second and then a third particle of ether are set in motion, *one after the other*, as at (*b*). When it is borne in mind that there are no gaps in the luminiferous ether, this transference of motion will perhaps be more easily understood. A ray of light is represented at (*b*) as just starting in the direction of the arrow to some distant object.

When the vibratory motion has been caught up by all the ether particles, we have the effect shown at (*c*), where all the dots are in motion except those at the extreme positions above and below the normal (dotted) line, these being at the turning point. The dots situated on the normal line are not at rest, but exactly half way between their extreme positions. Here we have a definite appearance of a wave, and if the dotted line be taken to represent the undisturbed surface of water, the positions and relative motions of the dots will fairly represent the motions of water particles when thrown into ripples.

Such transmission of motion from particle to particle cannot, then, be instantaneous all along the line, and, in this respect, the theory agrees with the facts, for light "travels" with a certain velocity which has been measured.

But, in the figure, the dots can only be represented as vibrating in the same *plane* as the paper, and such simple motion is only true of a ray of *polarized* light, as will shortly appear. In a ray of *ordinary* light, the vibrations lie in every conceivable direction about a fixed central point, so that when viewed from either end of the line, the dots would move in the directions shown at (*d*), and in all intermediate directions. Dispensing with the dots, a line of undisturbed ether particles may be more accurately represented by a continuous straight line built up of an innumerable number of points. When all these points are in vibration, the effect would be to *increase the thickness* of the line.

To further illustrate this we will employ a large model, and regard the wick of a candle as representing a line of ether particles at rest. A thin section of the candle contains a fragment of wick embedded in the centre of a disc of wax, and if this fragment could vibrate like a particle of ether, its vibrations would lie within the space occupied by the wax. As the whole candle may be regarded as built up of an infinite number of such sections, the wax represents vibrations of the central-lying wick.

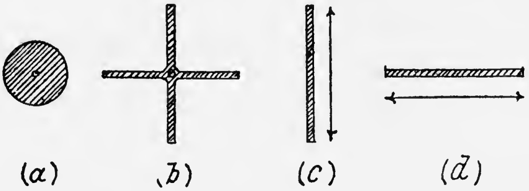

FIG. 14.

The section of candle shown at (*a*), Fig. 14, is perfectly symmetrical, and, of course, the same holds good for any section at right angles to the length of candle. Our model thus illustrates an important property of a ray of ordinary light. But on passing such a ray through certain crystalline minerals, this symmetry is lost, and the ray is said to be *polarized*. To illustrate this with our model we may suppose the candle to be passed from end to end through a machine, which presses the wax into two narrow channels at right angles to each other. A section of the "moulded" candle would then have the appearance shown at (*b*), and as the wax represents vibrations, we may express this in terms of "light" by saying that the vibrations have been confined to two planes, perpendicular to each other, and shown separately at (*c*) and (*d*). Moreover, the wax being equally distributed in (*b*), the number of ether vibrations in the direction (*c*) is exactly equal to the number in the direction (*d*). In fact, the original ray of light has been split up into two polarized rays of equal intensity, and as these rays do not pass through the polarizing crystal in the same direction, they can be separated.

This separation may also be roughly reproduced if the candle-moulding machine be fitted with two parallel cutting edges, set perpendicularly. The candle would first be moulded into the form (*b*), the two horizontal limbs then cut away, and the remainder emerge as a ribbon of wax, whose section is represented at (*c*). If the cutting edges be set horizontally, the ribbon of wax will emerge from the machine in the position (*d*). In either case the ribbon represents a ray of polarized light ; that is to say, a ray in which the vibrations lie in a *single plane*.

Polarized light cannot be recognised as such by the eye, but when examined through a second crystal (similar to that producing the polarized ray), it is found that light is only freely transmitted by the second crystal when certain axes of both crystals lie in the same plane. In all other positions, the second crystal is less transparent to the polarized ray, and appears to become opaque when the said crystalline axes are at right angles to each other. The first or polarizing crystal is termed *the polarizer*, and the second crystal, *the analyzer*. This variable transparency of the second crystal appears to be due to internal structure, which for our present purpose may be represented as fibrous, like wood. On this assumption, the observed facts might be expressed by saying that when the ether vibrates *with the grain* of the polarizer, such vibrations will be transmitted in a similar direction through the analyzer, but not *against the grain* of the latter.

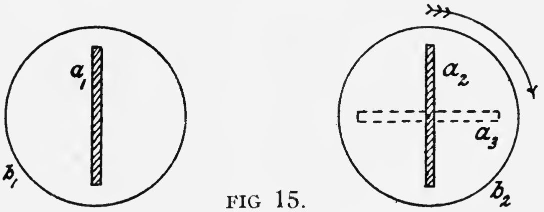

FIG 15.

Appealing once more to our model, let one end of the moulding-machine terminate in a metal plate (*b*), Fig. 15, having two parallel cutting edges forming a narrow slot (*a*), and let two such machines be arranged opposite to each other.* Now if the two slots (a^1) (a^2) are both perpendicular, the ribbon of wax emerging from (a^1) will freely enter (a^2). If, however, the plate (b^2) be turned on its centre in the direction of the arrow until the slot (a^2) is in the position (a^3), the tape of wax will no longer pass from one slot to the other unless twisted.

Substituting polarizing and analyzing crystals for the plates (b^1) (b^2), the reader should now have some idea of the peculiar nature of a polarized ray according to the wave-theory of light.

Certain crystals and a few liquids possess the remarkable property of twisting a ray of polarized light so as to change the plane of vibration of the ether-particles. If, for example, a polarized ray, composed of vibrations in the perpendicular plane (*c*), Fig. 14. be passed through a solution of sugar, the plane of vibration is twisted round towards the horizontal plane (*d*). In fact, the effect would be similar to that of twisting the ribbon of wax emerging from the slot (a^1), Fig. 15, until the free end could be inserted in the slot (a^3).

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* In the figure the plates are represented *side by side* for he sake of clearness.

The angle through which the plane of vibration is turned depends upon two factors—the strength of the sugar solution, and the depth of liquid through which the polarized ray is caused to pass. By maintaining the depth of liquid constant, the polarized ray is twisted in proportion as the solution is rich in sugar, and this constitutes the basis of quantitative measurement adopted in the polariscope.

This instrument may now be briefly described as a horizontal tube containing a polarizing crystal at one end and an analysing crystal at the other. Between these there is inserted a tube filled with the solution to be tested, and closed at its extremities by glass plates so that the light may pass through the tube from end to end. The length of the tube thus regulates the depth (or thickness) of liquid to be optically examined. A lamp-flame being placed opposite that end of the instrument containing the polarizer, a beam of polarized light is passed through the tube containing the liquid, then through the analyzer, and finally reaches the observer's eye.

To measure the angle through which the plane of the polarized ray is twisted during its passage through the sugar solution, two methods are adopted ; the simplest being that in which the analysing crystal can be turned on its axis, like the plate (b_2) in Fig. 15. For this purpose the crystal is mounted in a tube, which can be rotated by means of a rack and pinion. When this is done, a pointer describes an arc opposite a fixed circular plate which is finely graduated at its circumference. When the pointer is opposite the zero of the scale the relative positions of the polarizer and analyzer are indentical, and the beam of polarized light will pass directly through the analyzer. But on inserting the " observation tube " filled with a solution of sugar only a part of the light is transmitted. On turning the analyzer round, a point is soon reached when the twisted ray of the polarized light is again freely transmitted, the position of the pointer then showing the angle through which the analyzer has been turned.

A more general arrangement, however, is to fix both the polarizer and analyzer, so that the latter freely transmits the ray received directly from the former. The optical activity of the sugar solution is then compensated by causing the twisted ray to pass through another substance capable of turning the plane of the ray in a reverse direction. Hence, one might say that the ray is twisted in one direction by the sugar solution and then twisted in the opposite direction by the " compensator," so that on reaching the analyzer the vibrations are in precisely the same plane as when the ray left the polarizer. As this type of polariscope will have to be described in some detail, we may now pass from theory to practice.

The first step is to unpack the polariscope and put it into working trim. The lower extremity of the brass pillar is to be screwed to the tripod base, and the upper extremity of same to the socket on the body of the polariscope. The latter is thus supported horizontally as shown in Fig. 16.

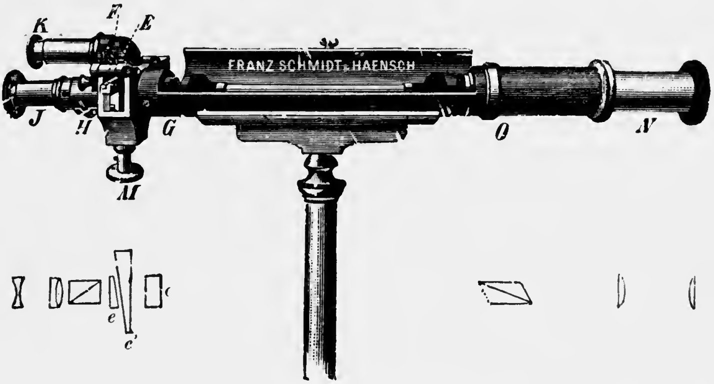

FIG 16.

The magnifier (*K*) is then attached in the position shown by means of two screws immediately over the letter (*H*). A ray of light entering this instrument at (*N*) will pass sucessively through the polarizer, situated at (*O*). the observation tube (shown in position), the compensator at (*E*), the analyzer at (*H*), and the eye-piece (*J*).

These optical parts are shown in their relative positions in the lower part of the figure, but only one of these—the compensator, need occupy our attention, and as this can be removed from the instrument it should be inspected by proceeding as follows:—Turn the screw (*M*) in either direction until the metal frame (*E*) (which is thus set in motion) ceases to move any further. Take hold of the projecting end of this frame and draw it gently forward in the same direction until it slides out of the instrument, observing carefully how it should be replaced. In the centre of the frame will be found a wedge-shaped piece of quartz and from the position of this wedge in its frame it will be evident that a ray of light passing from (*N*) to (*J*) must penetrate different thicknesses of quartz according as the wedge is moved into different positions by turning the screw (*M*). Now quartz and sugar solutions having *opposite* effects on polarized light, a certain thickness of quartz will exactly neutralize the "optical activity" of a certain quantity of sugar contained in the observation tube. As the length of the latter is constant, the optical activity of the enclosed solution can only vary as regards the quantity of sugar dissolved in the liquid, and for each percentage of sugar there will be some point on the quartz-wedge where the optical activity of the solution is exactly balanced by that of the quartz. This point is ascertained by means of the graduated scale attached to the top of the frame in which the wedge is fixed. When the latter is moved by turning the screw (*M*) different numbers on this scale are brought opposite a fixed pointer; both the pointer and scale being visible through the magnifier (*K*).

The compensator must now be replaced by inserting the proper end of the frame in its "guides," and pushing it forward until it can be moved by the screw (*M*) alone. On no account must force be used either in removing or in replacing the frame.

Our next step will be to arrange the polariscope and its lamp on one of the two tables mentioned in Chapter IV, and as it is further necessary to screen the instrument and observer from all other sources of light, some special arrangement is necessary if a dark room be not available close to the laboratory. The table is placed against the wall in a corner of the room, and is screened off by a curtain of dark serge suspended from a rod fixed near the ceiling. This curtain should reach to the floor and be a few feet wider than the table is long. The observer sits at the free end of the table with the eye-piece (*J*) of the polariscope facing him, and immediately above the edge of the table so that observations can be made comfortably. The lamp is next lighted and placed opposite the end (*N*) of the polariscope; a distance of six inches being left between that end and the bull's-eye of the lamp. The height of the latter is adjusted (by means of the telescopic rod and screw at its base) to bring the bull's-eye exactly in line with the horizontal axis of the polariscope. These preparations being complete, chalk marks are made on the table around the bases of the polariscope and lamp so that their relative positions may be always maintained.

THE OPTICAL EFFECT. The effect of introducing the observation tube filled with a solution of sugar between the polarizer (*O*) and analyzer (*H*), or of moving the quartz wedge by turning the screw (*M*) is to diminish or increase the quantity of light passing through to the eye at (*J*). Now the eye cannot detect slight differences in quantity of light (or shades of colour) unless the two illuminated (or coloured) objects can be compared simultaneously. With a little practice the eye can be trained to detect very minute differences by this method of contrast, and this fact is very ingeniously utilized in the optical construction of the polariscope.

Remove the observation tube from the instrument and carefully focus the eye-piece (*J*) by drawing the flange out or pushing it in. The *field of vision* appears as a disc, one half of which is shaded. If the quartz-wedge be moved in one direction (by turning *M*), the unequal illumination of the *field* increases; if moved in the reverse direction, the *field* becomes more uniform, until it finally assumes the appearance of a uniformly lighted disc, divided centrally by a fine vertical line. The focus of the eye-piece (*J*) must now be adjusted until the dividing line is clearly visible. This appearance is disturbed by the slightest turn of the screw (*M*), although the motion thus communicated to the quartz-wedge frame cannot be detected by the eye. The sensitiveness of the polariscope as a measuring instrument depends, therefore, on the ease with which the exact position of the wedge can be adjusted by the eye.

If the illumination of the *field* does not become perfectly uniform by manipulating (*M*), this may be due to the lamp being out of line with the polariscope. The latter can be turned from side to side owing to the screw-connection with the upright pillar, and it is therefore always necessary to point the polariscope body towards the bull's eye of the lamp. But the height of the lamp may be at fault, and in order to detect this, the field should be viewed through (*J*) while an assistant raises or lowers the body of the lamp, after slackening the screw near its base. When the correct height has been found, this screw is tightened up.

READING THE SCALE. On now applying the eye to the magnifier (*K*) and carefully focussing same, two scales will be visible. The uppermost scale is attached to the moveable quartz-wedge; the lower and shorter scale being a fixture. If a neutral "field" is still visible through (*J*), the zero lines of both scales should be opposite each other, and the reading is nil—no sugar being present. Other parts of the scale may be brought into view by turning the screw (*M*). For example, in Fig. 17, the fixed zero lies between 30 and 31 of the scale, and we have now to explain how a more exact measurement can be made by the use of the fixed scale or "Vernier."

The divisions on the latter are smaller than those on the scale;

ten of the former corresponding to nine of the latter. Consequently, when the 30-line on the scale coincides exactly with the zero-line on the Vernier, the tenth line to the right of zero coincides with line 39, while the intermediate lines (1 to 9) do not coincide with any line on the scale. In moving from this position to that represented in Fig. 17, the Vernier-lines 1 to 7 are *in turn* brought opposite certain lines on the scale. On moving the scale further still, the same occurs to the Vernier-lines 8, 9 and 10. But during these ten *successive* movements, the Vernier-zero has only passed from line 30 to line 31 of the scale, so that this unit has been measured in ten sub-units, or tenths. The correct reading represented in Fig. 17 is, therefore, 30 plus seven-tenths, or 30·7, because the Vernier-zero is beyond the line 30, and the seventh line to the right of zero coincides with a line on the scale.

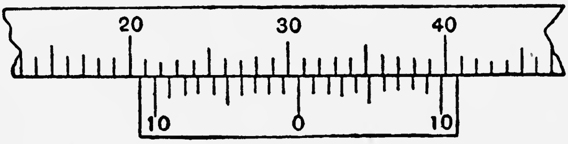

FIG. 17.

The reading of the scale is much less complicated than would appear from our instructions, but the following general rules will be found applicable to all points on the scale except the zero-point.

(*a*) If the Vernier-zero exactly coincides with a line on the scale, record the number of that line as the correct reading (a whole number).

(*b*) In all other cases record (as the whole number) the scale line which lies to the left of the Vernier-zero. Then observe which Vernier-line (from 1 to 9) *to the right of zero* coincides with a line on the scale, record this as *the tenths* and add same to the whole number already found.

FILLING THE OBSERVATION TUBE. Two glass tubes will be found in the polariscope case; one being 200 millimetres in length, the other 100 millimetres. An additional 200mm. tube of metal will answer our present purposes, so the two glass tubes, together with the spare cover-glasses and rubber-washers, may be left in the polariscope case.

Unscrew the caps from the ends of the metal tube, and polish the cover-glasses with a soft cloth. Inside each cap is a rubber washer which need not be removed, and must never be omitted. Replace one cover-glass and cap, screwing on the latter until it ceases to move freely. A *slight* additional turn of the cap will then ensure perfect contact between the cover-glass and the flat end of the tube. Now stand the tube upright on its capped end and fill it completely with clear rain-water, so that the liquid surface rises slightly above the open end of the tube. Holding the second cover-glass horizontally by its edges, slide same into its position on the top of the tube without leaving any air-bubbles beneath the glass and without wetting the upper surface of same. The former occurs when there is not sufficient water ; the latter when there is too much ; the happy medium must be found by actual trial. Finally, the second cap is screwed " home " gently, and the exterior of the tube wiped dry. The two cover-glasses now confine a column of liquid of exactly the same length as the tube.

The above instructions are to be followed when filling the tube with clarified juice, sugar solutions, etc., always bearing in mind the following points :—

1. The cover glasses must not be scratched or chipped. They should be polished immediately before use.

2. The rubber washers should be examined occasionally and replaced by new ones when they become hard and brittle.

3. The interior of the caps should be wiped before use, thus removing the surplus moisture from the washers. The caps must on no account be screwed tightly on to the tube.

4. If more than one solution is to be examined in the *same* tube, this must be rinsed out several times before being filled.

5. It being important that the tube and its contents should have the same temperature as the polariscope, care should be taken not to handle the tubes more than is absolutely necessary.

ADJUSTING THE ZERO-POINT. The observation tube, filled with pure water, is now placed in position on the polariscope and covered by the hinged flap. The eye-piece (*J*) must again be focussed and the screw (*M*) manipulated until both sides of the *field* are equally illuminated and the dividing line sharply defined. Raising the eye to the magnifier (*K*), the zero-line of the scale should coincide with the zero-line of the fixed Vernier, there being no sugar in the observation tube.

Whether it does or not, the exact reading is ascertained by the rules given above. But if the Vernier-zero lies to the left of the scale-zero, this indicates a *minus quantity*, and in this case the Vernier-lines *to the left* of the zero represent the tenths. If, for example, the Vernier-zero lies between the scale-zero and the next scale-line to the left, ascertain which line on the left-hand side of the Vernier coincides with some line on the scale. Assuming the third line of the vernier to be in this position, the correct reading would be —0.3 (all readings to the right of the scale-zero being *plus* quantities).

Whatever be the reading found, a single observation cannot be relied upon even in the case of an experienced observer. The beginner must, therefore, make sure of his ground by repeating the observation until he has recorded ten readings. After each reading of the scale has been noted down, the screw (*M*) is given a half turn in order to disturb the neutral appearance of the field, which must then be restored as accurately as possible before the next reading of the scale is taken. Finally, add up the *plus* readings separately from the *minus* readings. Subtract the smaller total from the greater, and the remainder, divided by ten, will represent the mean value of the ten observations. Even this result is only approximately correct, because the actual readings will probably differ too much from each other. As the eye becomes trained to the work, these differences will become less and less so that instead of taking ten readings, one may be contented with five, or even three.

The mean-value of ten readings may be accepted as sufficiently accurate when the two extreme readings do not differ by more than 4 divisions of the vernier (for example, +0·2 and —0·2; +0·3 and —0·1; 0·0 and +0·4). If this mean value is exactly zero, the instrument requires no adjustment.

Let us, however, assume a mean value of —0·2. Adjust the screw (*M*) so as to obtain this reading on the scale, when the quartz-wedge will, of course, be in its true position, giving a perfectly uniform illumination of the *field*. The small key provided with the instrument is now inserted in the socket near the quartz-wedge frame and on the observer's *left*. On viewing the scale through (*K*) whilst turning the key, it will be seen that the vernier is thus moved while the scale is stationary, and the key must be turned in which ever direction will bring the vernier-zero into exact coincidence with the scale-zero. This being done, and the key removed, the screw (*M*) is given a half-turn and another series of observations made. If the mean value of —0·2 before adjustment was accurate, the mean value after adjustment should be exactly 0·0.

We do not advise the beginner to attempt this adjustment until he has had several weeks of practice with the instrument. Each day the observation tube should be filled with water and the mean of ten readings taken as the " zero-reading." All readings of sugar solutions being corrected by deducting the " zero-reading " when this is *positive*, and adding it when it is *negative*.

When two or more observers use the same instrument, it does not follow that they will obtain the same reading at the zero or any other point of the scale. Slight differences of eye-sight introduce what is known as the " personal equation." But this difference being a constant one, it is eliminated when each observer corrects his readings of sugar solutions by his own reading at the zero-point of the scale.

THE HUNDRED-POINT OF THE SCALE. Having now set the polariscope in proper working order, attention must be directed to the other limit of the scale, marked 100, and *which corresponds to the thick end of the wedge.*

As sucrose is optically active only in a state of solution, polariscope makers have to adopt a solution of standard strength when graduating their instruments. The "Ventzke Scale" of our polariscope is based on the optical activity of a solution of pure sucrose of a certain density, when examined in a 200 m.m. tube. That position of the quartz-wedge which exactly neutralizes the optical activity of the solution is then marked 100 on the scale. The taper of the wedge being uniform, it only remains to divide the space lying between the zero and the 100 mark into 100 equal parts.

But, although Ventzke's scale is still adopted, his method of fixing the strength of the solution has been abandoned; it being more convenient to dissolve a known weight of substance in a known volume, than to ascertain the exact density of the resulting solution. The density selected by Ventzke corresponds to a solution containing 26·048 grams of sucrose in 100 cubic centimetres. To minimize the inconvenience of this odd weight, special weights are supplied with the instrument ; one, the " normal weight " having the above value ; the other, or " half-normal weight " of 13·024 grams.

The standard solution is prepared by dissolving the normal weight of absolutely pure sucrose in sufficient water to give precisely 100 c.c. of solution. When a column of this solution, 200 mm. in length is examined in the polariscope, the uniform illumination of the *field* is only secured by moving the quartz-wedge into its maximum position, corresponding to the 100 point on the scale.

It is thus possible to convince oneself that the quartz-wedge has been accurately constructed, and also that the two extreme positions of the wedge are accurately indicated by the scale, but many minute precautions are necessary before the skill of the instrument maker can be called in question. We shall presently describe a much simpler method of testing the accuracy of the instrument, but if the standard solution be prepared and examined, the beginner will have a clearer idea of the relation between the normal weight and the graduations of the scale.

In Chapter VI, full directions were given for preparing a 20% solution, so that it is only necessary to substitute the *normal polariscope* weight for the 20 gram weight then used, and to work with pure sucrose instead of with raw sugar. As such a pure solution does not require to be clarified with sub-acetate of lead, the contents of the measure flask have merely to be diluted exactly to the 100 c.c. mark and then thoroughly mixed. The observation tube is twice rinsed with this solution, then filled, and placed in position of the polariscope.

The two halves of the *field*, as seen through (J), will now be strongly contrasted ; this change being, of course, due to the optical activity of the sugar solution. The uniform illumination of the *field* has now to be restored by bringing the quartz-wedge into play, and several complete revolutions of the screw (*M*) will be necessary before the two halves of the optical field are again equally bright. The mean of several readings should be ascertained as in the case of zero-point, and if this final result differs from 100, it is far more probable that the manipulations have been faulty than that the instrument is inaccurate.

The result may, of course, be checked by weighing out another quantity of pure sucrose and repeating the manipulations more carefully. This should be done if only to assure one's self that the instrument is not *alone* at fault. All such results will probably fall short of the exact 100 because we have ignored the influence of temperature on the optical parts of the polariscope. Without entering into rather complicated details, it will be sufficient for our present purpose to assume that when every error is avoided the normal-weight-solution of pure sucrose would give a mean reading of 100·0 on the scale.

If, then, we prepare a normal-weight-solution of any impure saccharine material and repeat the foregoing manipulations, we shall obtain a mean reading of the scale which expresses *the percentage of sucrose in the material tested.* That this desirable result is not obtained " by magic " should now be clear, for we have tested a substance containing 100% of sucrose and obtained a (corrected) reading of 100·0, whereas a liquid entirely free from sugar gives a reading of 0·0.

With ordinary care, the polariscope is not likely to get out of order, even when in daily use. Should it receive any accidental knocks the optical parts may become displaced and the instrument rendered useless. Hence, it is very desirable to check the readings of the instrument from time to time, both at zero and at some other point of the scale. In the latter case the standard solution may be conveniently replaced by what are known as " standard quartz plates," and it is necessary to explain that there are two varieties of optically active quartz ; one twisting the polarized ray *to the left* (the quartz-wedge), and the other twisting the ray *to the right* (the standard quartz plate). Standard plates of different thicknesses are constructed for testing different points on the scale, but a plate giving a reading of 96 will be sufficient for our purpose. The plate is mounted at one end of a short metal tube which takes the place of the observation tube for liquids. It is worth noting that a comparatively thin plate of quartz has an optical activity equal to a sugar solution 200 m.m. in thickness ; also, that the *right-handed* optical activity of the standard quartz plate is neutralized by an *equal thickness* of the *left-handed* quartz-wedge when the latter is moved into the required position. Each standard plate is furnished with a printed table of corrections for temperature, with instructions for using same.

This concludes our examination of the methods used in the laboratory. The reader has been instructed in the use of the balance, the measure flask, the hydrometer, and the polariscope, and he has now to practice the manipulation before proceeding further. Samples of raw sugar, molasses, etc. will form excellent material for practice, several solutions of each sample being prepared and polarized until fairly concordant results are obtained. The density test may be practiced with samples of raw juice, but as this liquid requires some preliminary purification, we recommend diluted syrup, commencing with one part of syrup to two parts of water, and then gradually increasing the dilution by mixing with small additions of water, observing the densities at each step.

Those who have been unable to follow our *theoretical* explanations need not be deterred from carrying out our *practical* instructions.

PART III.

Simple Methods of Chemical Control.

CHAPTER IX.

THE CONTROL OF THE MILL.

We have now to explain how the tests described in the preceding section may be employed in connection with the factory work. Our object will be to keep an account of the sugar entering the factory so that the *output* may be compared with the *imports.*

Such an account should commence with the weight of sugar in the canes ground, but as this involves many difficulties, it will be more satisfactory to base our control on the sugar in *the juice.* But since the loss of sugar during extraction of the juice may sometimes exceed all other losses put together, some observations on the mill work will first claim attention.

The appearance and "feel" of the megass are useful guides to the practical man, but such general indications require to be occasionally confirmed by some kind of practical test. It being much easier to measure the amount of moisture than of sugar left in the megass, we proceed to :—

THE MEGASS TEST.

This is what is called a "factory test," it being necessary to treat a rather large quantity of megass in order that the coarse and finer portions may be duly represented in the sample. The following apparatus will be required :—

Wire cages to hold 10 pounds of loosely packed megass.

A hot-air drying chamber in which the cages are placed.

A spring balance for weighing the cages before and after drying. The last is included in the list of apparatus given in the appendix, but the other items are constructed as follows :—

MEGASS CAGES. These are rectangular boxes measuring 12in. × 8in. by 36in. deep, and are constructed of No. 7 iron wire gauze (mentioned in the list). To make one cage, cut off a piece of gauze, 3ft. × 3ft. 4in. and fold it at a distance of 8in. from one of the 3ft. sides. Make another fold in the same direction, at a distance of

12in. from the first, and a third fold at a distance of 8in. from the second. Open out these folds until they form rectangular bends, and lace the free ends together to form the fourth angle. This rectangular "tube," 36in. long, only requires a lid and a bottom to be converted into a box or cage. The ends of the "tube" must first be stiffened by inserting rectangular hoops of stout iron wire or of thin iron rod, the sides of the hoop measuring exactly 12in. × 8in., which are securely laced to the the gauze with lacing wire.

The lid and bottom of the cage are made from two pieces of gauze measuring 14¼in. × 10¼in. These measurements allow for 1in. to be turned up all round, leaving a central area of 12¼in. × 8¼in. The method of folding these pieces after splitting the corners will be sufficiently obvious. One piece is then laced to one end of the gauze "tube" to form the bottom of the cage, whilst the other piece serves as a detachable lid. To enable the cage to be suspended from the hook of the spring balance, a loop of strong wire is secured to the uppermost iron hoop, this loop folding inwards when the lid is put on. (The cage is weighed without the lid).

Four such cages are required and it is convenient to make them of uniform weight by proceeding as follows:—Suspend the cages from the hook of the spring balance and ascertain which is the heaviest. Attach to this cage a small piece of sheet lead, which may be stamped "No. 1." Note the exact weight and then load each of the lighter cages with larger pieces of lead until these correspond in weight with No. 1. These lead tabs are marked No. 2, 3, and 4. The empty cage, without lid, will weigh about 3lbs. and will hold 10lbs. of loose megass. When filled the cages are heated in the:—

DRYING CHAMBER. As a moderate temperature is sufficient, the heat radiated by the brickwork of one of the furnaces may be utilised as follows:—Construct a strong wooden box without lid 6ft. × 3ft. 6in. × 2ft. 6in. deep, but omitting one of the smaller sides (*i.e.*, 3ft. 6in. × 2ft. 6in.). Place this box on end against the furnace wall so that the open side is uppermost, and you have the drying chamber shown in Fig. 18.

A large hole cut near the base of each side admits cold air, which is rapidly heated by contact with the brick work and finally escapes at the top of the chamber. An upward current of air is thus produced, which attains its maximum temperature near the top of the chamber where two cages of megass are placed. The latter are

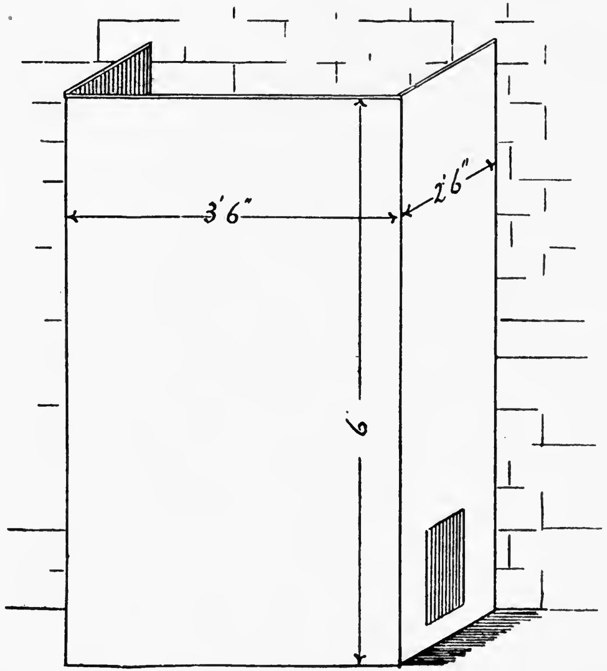

FIG. 18.

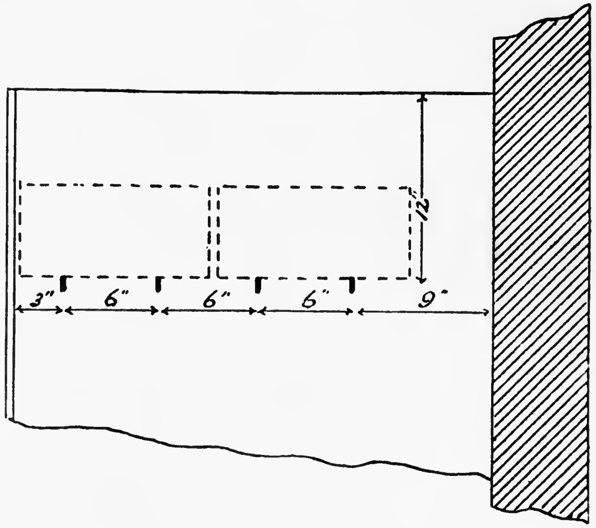

FIG. 19.

supported horizontally on a shelf made of four parallel bars (two under each cage) as shown on a larger scale in Fig. 19, which represents a side-view of the upper part of the chamber ; the furnace-wall being shown in section. These bars are of flat iron rod (about 4ft. long, 1in. wide, $\frac{3}{8}$in. thick) and are supported in holes cut in the side of the chamber in the positions indicated. The cages are shown in section by dotted lines.

The open top of the chamber affords easy access to the shelf when placing the cages in position or removing them after drying. The box must be constructed of boards which have been previously exposed to heat, warping of the joints being further minimised by banding with iron straps. It should rest on a level flooring, and be firmly secured in position against the furnace wall by means of a buttress.

The temporary structure, described and illustrated above, possesses the advantage that it can be moved from place to place (*i.e.*, nearer to, or further from, the hottest part of the wall). When a suitable position has been found, a permanent brick chamber can be built on the same lines.

SAMPLING. As the first few tests should be made in duplicate, two cages have to be filled with *the same* megass as follows :—If the megass is conveyed away from the mill by a "paddle-elevator," the contents of a well-loaded "paddle" should be withdrawn at intervals of one minute, and the megass transferred to the cages ; half to each. Similarly, when the megass is carried from the mill by coolies, a handful is taken from each load and divided between the two cages. The sampling is continued until the cages are filled.

WEIGHING. One of the iron brackets (furnished with the spring balance) should be screwed to an upright near the mill, at a height of about 5 feet from the ground, so that the cages may be weighed on the spot. Any *odd* weight of megass may, of course, be taken for the test, provided that the net weight is about 10 pounds, but the subsequent calculation is simplified by taking exactly 10 pounds, by adding or removing some megass as may be necessary. The advantage of having all the cages of the same tare will now be appreciated.

DRYING. The cages are next closed and placed horizontally in the drying chamber ; a clearance of six inches being left between the furnace wall and the nearest cage (see Fig. 19). The drying will then proceed without further attention and will be complete in about 10 hours. Should the megass become charred during drying, the temperature of the drying chamber is too high, and another position must be found for it. Charring is most likely to occur in the cage lying nearest to the wall, hence our object in duplicating the test. A slight darkening in colour may be ignored if no appreciable loss in weight occurs after the dry megass has been re-weighed and returned to the chamber. When building a brickwork drying chamber, it is necessary to remember that this will give a rather higher temperature than the wooden model in the same position.

RE-WEIGHING. It economises time to re-weigh the cages near the drying chamber, the spring balance being suspended from a second bracket fixed to a suitable upright. The cages may, of course, remain for more than 10 hours in the drying chamber before being re-weighed, but it is advisable to ascertain what minimum time should be allowed by re-weighing after, say, 8 hours and then at intervals of 2 hours until there is no further loss in weight.

CALCULATION. The result should be recorded in connection with general observations on the mill work, for example :—

The Megass appeared to be well crushed.

	lbs.	ozs.
Cage No. 1 + 10 lbs. megass	=14	3
After drying	= 8	10½
	5	8½ =
		5.53 lbs
Moisture	=55.3%	

This result is fairly satisfactory for a three-roller mill, but should the percentage of moisture approach, or exceed, 60%, this will indicate bad work, and call for the engineer's attention to the adjustment of the rollers. In the case of double crushing the moisture should not much exceed 50%, 55% being unsatisfactory, but as the percentage of moisture is not a true measure of the efficiency of the mill work, it is impossible to give more exact data. The moisture test serves to confirm what the eye suspects and should therefore be applied only when the appearance of the megass suggests inferior extraction.

CHAPTER X.

THE CONTROL OF THE CLARIFICATION.

The tempering of cane juice is still generally regarded as an " art " requiring no scientific knowledge. Yet this kind of " artist " is not as independent of science as he thinks, for he is constantly handling the Baumé Saccharimeter and little slips of coloured paper ; the former telling him the density of the milk of lime added to the juice ; the latter, when sufficient lime has been added. He also makes *an experiment* whenever he varies the charge of lime-milk per tank of juice, and *is guided by the result.*

In order that these and similar tests may be used intelligently, we propose to study the chemical changes which raw juice undergoes by means of a few simple experiments.

1. Collect some juice from the mill and transfer it to the filtering apparatus shown in Fig. 11 (chapter VI). The juice does not flow through the filter because the pores of the paper are clogged by an impurity in the juice called *albumen.* This is found in all vegetable juices, and closely resembles *animal albumen*—or " white of egg."

2. Whisk up the white of an egg and add a teaspoonful to a pint of clean water in a bottle. On shaking the latter a dilute solution of albumen is obtained, with which Experiment 1 should be repeated (using a fresh filter paper). Whereas water passes through the filter very readily, this albumen solution behaves in much the same way as raw juice containing *vegetable albumen.*

3. Half fill a test tube with the albumen solution and fix the tube in a test-tube holder. This is an arrangement for holding the tube when the latter is to be heated, and consists of a wooden handle with two brass springs which can be closed round the upper part of the test tube by means of a sliding ring. Fill the spirit lamp with strong alcohol and arrange the wick to give a small flame, which is allowed to play upon the bottom of the tube, gently shaking the latter occasionally. The heated solution rapidly turns milky because

albumen is rendered insoluble by heat. In a hard-boiled egg this action of heat is still more striking. This milky appearance disappears on boiling the liquid because the albumen separates into small solid particles which are suspended in pure water, and can now be filtered with the greatest ease ; the whole of the albumen being left on the filter paper whilst pure water drips into the receiver.

4. Heat a little raw juice in the same manner, and after it has boiled, withdraw the tube from the flame and examine the liquid in a good light. Flocculent particles of *vegetable albumen* will be seen descending towards the bottom of the tube, but no amount of boiling will render the juice clear.

5. Pour the heated juice upon a fresh filter paper. It filters through very slowly, and the filtered juice is anything but clear. Other impurities are present which heat alone will not remove.

6. Dip a slip of blue litmus paper into the raw and the boiled juice ; it is reddened in both cases. The red colour will be more intense if juice from sour canes is tested. Litmus is a vegetable blue which is turned red by acids.

A later experiment will prove that when a solution of sugar, containing an acid, is heated, a part of the sugar is converted into an uncrystallizable form ; in other words, the sucrose is destroyed and new substances produced therefrom. The addition of an alkali to the juice prevents this change, because alkalies combine with acids to form salts which are neither acid nor alkaline. Thus, table-salt can be made by adding a strong alkali, caustic soda, to a strong acid—muriatic acid. The properties of these two substances entirely disappear on mixing, and a new substance is formed. This is a case of chemical change as distinct from blending or mere mixing. Alkalies restore the blue colour to litmus which has been reddened by an acid, and advantage is taken of this fact in testing for alkalies. Red litmus paper is made by steeping paper in an *acid* solution of litmus, and is turned blue by alkalies but not affected by acids. On the other hand, blue litmus paper is turned red by acids but is unaffected by alkalies. Neutral litmus paper is neither blue nor red, but has a faint violet colour ; it serves to detect either acids or alkalies, and is much more sensitive than the blue and red papers.

7. Shake some milk of lime with rain-water in a large bottle. The bulk of the lime remains insoluble, but a small quantity dissolves in the water, and this lime-water can be decanted off clear after a

few hours. Dip a red litmus paper into the clear lime water—it is turned blue. Apply the same test to some milk of lime—the blue colour is much stronger. A small quantity of milk of lime is sufficient to neutralize a very large quantity of acid juice; but as we require to add very small quantities of lime in the following experiments, the lime water is preferable.

8. Add a small quantity of clear lime water to a few ounces of raw juice; mix thoroughly, and test with blue litmus paper. Repeat these operations until the test paper shows no trace of acid, adding the lime-water cautiously as this point is approached. Now test the mixture with a red paper, which will turn blue if too much lime-water has been added, in which case add a little more of the (acid) juice until the red papers show no alkalinity. Test the liquid finally with a neutral paper and add juice or lime-water until the mixture is exactly neutral. Add equal volumes of this neutral juice to four clean test tubes, supporting the latter in the test tube-stand. Note that the *cold* tempered juice does not clarify on standing.

9. Heat one of the tubes until the juice boils, and allow to stand. Clarification is now effected, the impurities separating in the form of a sediment, leaving the juice bright and clear. On transferring the contents of the tube to a filter paper, filtration proceeds very rapidly.

10. The three remaining tubes of neutral juice are now treated as follows:—The first is rendered faintly acid by adding two or three drops of raw juice. The second is made faintly alkaline by adding a drop of lime-water. The third is left neutral. Wipe the outside of each tube perfectly clean and heat each, in turn, until the juice commences to boil, and allow to stand for ten minutes. Although the proportion of lime to juice differs in each tube, clarification is equally good in each case so far as *appearances* go.

11. Decant off the clear juices into three clean tubes, add two drops of lime-water to each, and again heat to boiling. A second precipitate will be formed in the tube containing acid juice, a smaller precipitate in that containing neutral juice, and no precipitate in the alkaline juice. The conclusion to be drawn is that *appearances are deceptive* since only one out of the three samples had been properly tempered in the first instance.

In conjunction with heat, lime produces a heavy precipitate consisting of various impurities, some of which were originally dissolved in the juice, whilst others, merely in suspension, are mechanically carried down by the former. All these impurities can be completely separated from the juice by subsidence or filtration. This visible effect is naturally the most striking, but our study of clarification will not be complete until we have learnt what *invisible* effects are simultaneously produced when raw juice is heated with and without the addition of lime.

Solutions of sugar, even when pure, cannot be continuously heated without some change taking place. This is termed *inversion*, and consists in the conversion of the sugar (sucrose) into another variety (invert sugar) which cannot be crystallized from its solutions. Hence, as regards sugar-making, inversion is the destruction of the raw material of the factory. Whereas this change is very gradual in the case of neutral solutions of sugar, it is promoted by the presence of acids, and our next experiment is a very instructive one.

12. Prepare a 10 per cent. solution of loaf sugar by following the directions given in Chapter VI, and filter if necessary. Fill the observation tube with the clear solution and note the scale reading of the polariscope when the optical field has been neutralized by adjusting the screw (*M*). Empty the observation tube into a 50 c.c. flask, and fill the latter to the lower mark with more of the solution. Now fill the flask to the upper mark with muriatic acid, and empty the same into a larger flask in which the acid and juice can be mixed by shaking. Immerse the body of the flask in boiling water or hot juice for ten minutes, and allow to cool. Treat another 50 c.c. of the solution in the same way, but without adding any acid. When quite cold, examine the two solutions in the polariscope (using the *glass* observation tube). The neutral solution will give almost the same reading as before heating, whereas the acid solution will give a *negative* reading (*i.e.*, to the left of the scale-zero instead of to the right). *The* 10 *per cent. of sucrose has disappeared,* having been transformed into *invert sugar* (glucose).

Fortunately the acids normally present in raw juice are not nearly so active in this respect as muriatic acid, and being present only in minute quantities, inversion takes place very gradually.

Finally, we may inquire what happens when the juice is overlimed, and thus rendered distinctly alkaline. In the first place, the lime dissolves in the juice, so that any excess of this agent merely contaminates the juice instead of purifying it. Secondly, an excess of lime attacks the glucose or invert sugar, combining with it to form organic lime salts, which are gummy, dark in colour, and cause trouble at a later stage; the colour of the alkaline juices in experiments 10 and 11 being due to this. Thirdly, on greatly increasing the proportion of lime beyond that required to neutralize all acidity, the lime attacks the sucrose, forming sucrate of lime, a compound from which the sucrose can only be extracted by special treatment.

We are now in a position to repeat some of the foregoing experiments in the factory, and, in what follows, it will be assumed that the juice is heated nearly to boiling point by means of juice-heaters, and is then tempered in open tanks, or "clarifiers." This is the most general arrangement, but where others exist it will be easy to modify some of the instructions which follow.

TEMPERING JUICE FOR NON-CHEMICAL SUGAR.

The first step towards controlling this operation is to ensure that equal measures of lime-milk shall contain equal quantities of active lime as indicated by its density. A cheap Baumé hydrometer is sufficiently accurate for this purpose, and a density of 15°B. is a convenient working strength.

As the juice coming from the mill is of variable composition it might appear necessary to temper each clarifier with different quantities of lime-milk. By analysing samples of raw juice from each clarifier it would be possible to carry this out in practice, but the chemist would not then be available for other work. As, however, the juice is not liable to sudden fluctuations in quality, many successive tanks of juice can be similarly treated without much risk of over—or under—liming. But when either of these becomes apparent, the proportion of lime-milk is diminished or increased in subsequent tanks until the tempering is rectified; this proportion being maintained until the tests show that another change is necessary. This method has the advantage of simplicity and is the one most generally adopted.

The charge of lime-milk per clarifier of juice must, in the first place, be ascertained by trial, employing the tests described below; but, assuming that this quantity may be approximately guessed (from that required on the previous day), the essential thing is to be able to increase or decrease the charge *by small quantities.* A full charge is therefore measured out in, say, ten units, the size of the latter depending on the quantity of juice to be tempered. A cylindrical metal can, holding about half a pint, and soldered to a metal handle, answers the purpose admirably. If this is filled ten times for a "normal charge," the latter can then be varied by one-tenth, or, if necessary, by one-twentieth (by taking a half measure). The charge must be thoroughly stirred into the juice and the clarifier filled to the required level before the juice is tested.

To ascertain whether the juice has been correctly tempered we may resort to the following tests :—

1. Neutral litmus paper indicates when all acidity has been neutralized ; the intensity of the blue colouration serving as a rough measure of the alkalinity ; but this test fails to indicate what degree of alkalinity is most effective.

2. The latter point is ascertained by observing whether a further addition of lime produces any visible effect, as in experiment No. 11. A test tube, fixed in the holder, is plunged below the surface of the juice in the clarifier after partial subsidation. To half a test tubeful of the *clear* juice a little *clear* lime-water is added and the tube shaken. If the mixture remains clear, sufficient (or too much) lime was used for tempering ; if it becomes milky, the dose of lime-milk was too small. This test is more sensitive if the dilute lime-water be replaced by a stronger solution of lime prepared as follows. Dissolve half a pound of white sugar in a quart of rain-water, transfer the solution to a Winchester quart bottle, add some milk of lime, and shake thoroughly. The lime combines with the sugar (sucrose) to form sucrate of lime and this dissolves in the water. Sufficient milk of lime is added to render the whole milky after it has been shaken up several times. The excess of lime is then allowed to deposit as a sediment and the clear solution decanted off or filtered through a filter paper. The absence of any cloudiness or precipitate with this test is rather an indication of over-liming so that a faint turbidity should be seen if the tempering has been correct.

3. A third plan is to observe how the precipitated impurities settle in the tempered juice—whether rapidly or slowly ; also the colour and transparency of the clarified liquor. To this end a wide-mouth bottle is filled with the "muddy" liquor taken from a clarifier which has just been filled. Similar samples, collected from each clarifier, may be arranged side by side on a shelf fixed in front of a window near the tanks, so that the transparency and colour of

the juice may be kept under observation, whilst varying the charge of lime-milk added to each clarifier.

To sum up, juice which has been properly tempered should be faintly alkaline to litmus paper. The *clear* juice should give only a faint turbidity when mixed with a few drops of sucrate or lime. And, lastly, the insoluble impurities should settle rapidly, leaving the juice perfectly transparent and not too dark in colour.

In the practical application of these simple tests, it is only necessary to re-temper the juice when the test paper shows the juice to be still acid. In other cases it is sufficient to use the indications of the juice in one tank as a guide to the treatment of the next. For example, if the clear juice from tank No. 1 is very faintly alkaline to litmus paper but becomes cloudy when mixed with a drop or two of sucrate of lime, it is probable that this lot of juice has been slightly underlimed. The charge for No. 2 is therefore increased by one-tenth; that for No. 3 by another tenth, and so on, until the juice (say in tank No. 5) remains *almost clear* when similarly tested. The charge added to No. 5 can then be adopted for Nos. 6, 7 and 8, each of which are tested in turn.

TEMPERING JUICE FOR WHITE AND YELLOW SUGARS.

In this case the chemical treatment of the juice is more complicated than that already described, and differs somewhat in different factories. When sulphur is used for bleaching the juice, the weight of sulphur burned per hour should be known in order that the bleaching action may be increased or diminished at will. Similarly, with the other chemicals used. As the tempered juice is allowed to remain faintly acid to litmus paper, the sucrate of lime test is dis-dispensed with, and more reliance placed on the appearance of the juice in the sample bottles.

CHAPTER XI.

The Control of the Imports.

By *Imports* we mean the quantities of sugar daily entering the factory in the form of juice, and as these should exactly balance the exports plus the losses incurred during manufacture, a knowledge of the same is of primary importance in economic production. We would even claim that such a "balance sheet" is as necessary to the sugar producer as book-keeping is to the business man.

The subject of the present chapter may be outlined as follows:—An average sample of juice is submitted to *the optical test* and the result expressed as pounds of sugar per gallon of juice. The gallons of juice treated in the factory per day being also determined by utilizing the clarifier tanks as measuring vessels, we have only to multiply this number by the weight of sugar per gallon to obtain the weight of imported sugar; generally termed the *Indicated Sugar* (because indicated by the polariscope). Adding together the daily imports we arrive at the imports per week, month, or year. We proceed to consider these measurements in detail.

The Volume of the Juice.

As the juice is measured hot, certain calculations are called for in adjusting the working capacity of the clarifier tanks. The expansion of sugar solutions having been studied with great care, we may accept the following data as reliable. If a gallon of juice at 84°F. be taken as unity, then 100 gallons become:—

102·16 gallons at	180°F
102·85 „ „	185°F
103·03 „ „	190°F
103·27 „ „	195°F
103·45 „ „	200°F

The temperature of the juice is observed in a tank which has *just been filled*, the thermometer-bulb being kept under the juice whilst the reading is taken. As this temperature falls when the tubes of the juice-heaters become coated with scale and dirt, it is necessary to ascertain the minimum and maximum temperatures (before and after the juice-heaters are cleaned) in order to arrive at the mean working temperature.

From the data given above it is a very simple matter to calculate the height to which the hot juice should be allowed to rise so that its volume at 84°F. would be x gallons. The required level is then indicated to the workmen by means of the brackets described in chapter III.

SAMPLING.

The samples already taken for observing the appearance of the tempered juice (see page 73) are further utilised as follows. After the impurities have subsided, 50 c.c. of the clear liquor are withdrawn from every phial (indirectly from every clarifier filled) and united in a large stoppered bottle containing a minute quantity of bi-chloride of mercury to act as a preservative. This highly poisonous substance must be kept in the laboratory, and requires to be reduced to a fine powder before use. As much of this powder as will rest on the tip of the blade of a pocket-knife is dropped into the empty "sample bottle" every morning. The sample bottle can then be taken into the factory and kept on the same shelf as the phials of juice from which it is gradually filled. As a further precaution this bottle should be so labelled that the native workmen will not be tempted to taste its contents.

At the end of the day the sample bottle will contain equal volumes of juice taken from every tank, so that any small portions of *the mixture* will accurately represent the quality of the juice worked up in the factory during the day. The mixture must be thoroughly cooled before being tested or the analysis may conveniently be postponed until the following morning.

If the collection of the samples be left to the foreman in charge of the clarifiers, the total volume of the sample (measured by means of the 200 and 100 c.c. measuring flasks) serves as a check, since this volume (in c.c.) divided by 50 should give the number of clarifiers filled during the day, if a sample was taken from each tank. Special care must, however, be taken in sampling the last two or three clarifiers, because the juice is then diluted with the water used for washing down the mill.

In all such cases, it is necessary to strictly follow the rule that whatever liquor passes to the evaporator must first be measured and sampled. If any clarifier be only partially filled with juice or " sweet water," the volume in gallons must be calculated from the depth of liquor, and the quantity added to the sample bottle must be proportionally *less than* 50 *c.c.*

Our reason for sampling the juice after it has been heated and tempered, may now be briefly explained. A sample of the raw juice, caught from the mill-bed, can only represent the comparatively small volume of juice then flowing. Even if samples are taken every half hour, or at intervals corresponding to the filling of each clarifier tank, it is obviously impossible to sample more than a small portion of the total juice, and consequently variations escape detection if these happen to occur during the intervals between the taking of the samples. Secondly, the volume of the juice cannot be so accurately measured before as after heating, and it is advisable that the analysis should refer to the juice as actually measured.

Occasionally, however, it is desirable to examine the raw mill juice, in order to judge of the quality of some particular lot of canes. In this case a pint can should be completely filled, and left to stand for about twenty minutes in order to allow the air-bubbles to rise to the surface and the heavier suspended impurities to settle to the bottom of the can. The foam is then removed as completely as possible and the liquor carefully decanted into a hydrometer jar, placed on the laboratory sink. The jar is completely filled and any foam on the surface of the juice is blown off. With the exception of this preliminary treatment, the raw juice is analysed in exactly the same manner as the tempered juice.

ANALYSIS.

This includes the estimation of the sugar, as also of the total solid matters in solution (degrees Brix). From these data we can calculate the ratio of sugar per 100 parts of dissolved solids, or *Quotient of Purity*. In what follows it will be assumed that the reader is familiar with the practical instructions given in Part II.

THE OPTICAL TEST. A 100–110 c.c. flask is filled to the lower mark with the juice, 5.c.c. of basic acetate of lead added, and the contents diluted to the 110 c c. mark with water. The whole is mixed, filtered, and the clear filtrate transferred to the observation tube of the polariscope.

By way of example, let us suppose that the mean of five polarimetric observations gives a reading of 53·7, water (or the zero point) reading +0·2. The corrected reading of the juice will then be 53·7—·2 = 53·5. This number would indicate the percentage *by weight* of sugar in the juice *only* if the "normal weight" of juice had been diluted to 100 c.c. (see page 57). Similarly, the scale-reading would indicate percentage *by volume* if 26·048 cubic centimetres (instead of grams) had been diluted to 100 c.c. The assumed reading of 53·5 has therefore to be corrected, and the calculation may be made in two stages, as follows :—

(*a*) The juice was diluted by one-tenth (*i.e.*, 100 c.c. to 110 c.c.), hence the undiluted juice would have given a reading of

$$53{\cdot}5 + \frac{53{\cdot}5}{10} = 58{\cdot}85.$$

(*b*) If the undiluted juice reads 58.85 a solution of same, containing 26·048 c.c. per 100 c.c. would give a reading of $\frac{58{\cdot}5 \times 26{\cdot}048}{100} = 15{\cdot}33$; so that the sample contains 15·33 grams of sugar per 100 c.c.

This result is definite enough for the chemist, but to give it a practical meaning in the factory it is only necessary to re-state it thus :—

15·33 grams per 100 c.c.
= 1·533 pounds per gallon, since a gallon of water weighs ten pounds. To reduce the above calculation to its simplest form, let R stand for the scale reading of any sample of juice, then R × ·02865 = pounds of sugar per gallon of juice.

Even this calculation may be partly avoided by means of the Table on the opposite page, showing the "*pounds sucrose per gallon*" corresponding to the *whole numbers* of the scale reading. It is then only necessary to calculate the fractional part of the reading, in which case the simpler factor ·029 may be employed instead of ·02865.

Taking our former example, we find :—

$$\begin{array}{rrl} & 53{\cdot}0 \phantom{{}\times{\cdot}029} = 1{\cdot}519 & \text{(from Table).} \\ \text{and} & \underline{{\cdot}5} \times {\cdot}029 = \underline{{\cdot}0145} & \text{(by calculation).} \\ \text{Scale reading} = & 53{\cdot}5 \phantom{{}\times{\cdot}029 = {}} 1{\cdot}5335. & \end{array}$$

Omitting the fourth decimal if not greater than 5, this becomes 1·533, as calculated above. When the fourth decimal place is greater than 5, the third decimal place is increased by 1 ; thus, 1·5336 becomes 1·534.

TABLE II.

Polariscope Reading.	Pounds Sucrose per Gallon.	Polariscope Reading.	Pounds Sucrose per Gallons
30	·860	50	1·433
31	·888	51	1·461
32	·917	52	1·490
33	·946	53	1·519
34	·974	54	1·547
35	1·003	55	1·576
36	1·032	56	1·605
37	1·060	57	1·633
38	1·089	58	1·662
39	1·117	59	1·691
40	1·146	60	1·719
41	1·175	61	1·748
42	1·203	62	1·776
43	1·232	63	1·805
44	1·261	64	1·834
45	1·289	65	1·862
46	1·318	66	1·891
47	1·347	67	1·920
48	1·375	68	1·948
49	1·404	69	1·977

THE DENSITY TEST has been fully described already.

THE QUOTIENT OF PURITY. Assuming that the juice contains 1·533 pounds of sugar per gallon, and a density represented by 18·0 Brix, we have now to learn what percentage of the total dissolved solids consists of sugar. As the Brix scale indicates 18·0 % of dissolved solids *by weight*, we must also express the 1·533 pounds sucrose per gallon in terms of percentage by weight. From Table 1 (page 41) we learn that a gallon of juice at 18·0 Brix weighs 10·707 pounds, and :—

10·707 : 1·533 :: 100 : $x = 14{\cdot}318$ per cent. of sugar by weight.

In 100 parts by weight of juice, there are :—

Total solids (Brix)	18·0
Sucrose	14·318

and 18 : 14·318 : : 100 : $x = 79{\cdot}5$ *Quotient of Purity.*

Having measured the volume of the juice and ascertained its composition, we are now in a position to draw certain practical conclusions.

PERCENTAGE OF JUICE ON CANES.

Although the weight of juice extracted per 100 parts of canes is not a true measure of the work done by the mill, it is too familiar a figure to be wholly ignored and is frequently of interest in comparing the yields of juice from different varieties of cane, or from the same variety when grown on different soils.

As an example, we will take the figures on the first line in Record A (p. 82) namely, 298·5 tons of canes and 40,600 gallons of juice at 18·0 Brix. In Table I. (Chapter VII.) it will be seen that, at 18·0 Brix, 209·2 gallons of juice weigh one ton, and $\frac{40600}{209 \cdot 2} = 194 \cdot 1$ tons (as recorded in the third column of Record). This weight of juice being extracted, from 298·5 tons of cane, corresponds to a yield of $\frac{194 \cdot 1 \times 100}{298 \cdot 5} =$ 65·0 per cent., leaving a balance of 35·0 per cent. of megass.

INDICATED SUGAR.

The same 40,600 gallons of juice contain 1·533 pounds sucrose per gallon, and, therefore, represent $40{,}600 \times 1 \cdot 533 = 62{,}240$ pounds of imported or indicated sugar.

AVAILABLE SUGAR.

That proportion of the indicated sugar which can be crystallized is termed the *available sugar*, and varies with the purity of the juice, the efficiency of the factory appliances, and the skill of the pan-boiler.

From the manufacturing yields obtained in modern factories in Java, Dr. Winter has devised a formula for calculating the available sugar when the purity of the juice is known. It may be of interest to state that theoretical considerations led Mr. Carp, of Java, and Mr. Deerr, of Demerara, to almost identical conclusions.

Dr. Winter's formula was used in drawing up Table III.,* which obviates calculations. When the purity of the juice is expressed by a whole number, the available sugar is found in the second column of the Table; otherwise under one of the columns headed ·1 to ·9. For example, given a juice of 77·7 purity, we find 88·5 opposite the whole number—77, and under column headed—·7. This means that for every 100 parts of indicated sugar in such juice it should be possible to recover 88·5 parts in the form of crystals under the most favourable conditions. As the actual yield of crystals (of all grades) cannot be accurately ascertained before the end of the manufacturing season, the available sugar only figures in Record C.

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*Borrowed from Mr. Geerligs' "Methods of Chemical Control in Cane Sugar Factories."

TABLE III.

Showing what Percentage of the Indicated Sugar is available.

Purity	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9
77	88·05	88·1	88·2	88·25	88·3	88·4	88·45	88·5	88·6	88·65
78	88·7	88·8	88·85	88·9	89·0	89·05	89·1	89·15	89·25	89·3
79	89·35	89·4	89·5	89·5	89·6	89·7	89·75	89·8	89·85	89·95
80	90·0	90·05	90·1	90·2	90·25	90·3	90·35	90·4	90·5	90·55
81	90·6	90·7	90·75	90·8	90·85	90·9	91·0	91·05	91·1	91·15
82	91·2	91·3	91·3	91·4	91·45	91·5	91·6	91·6	91·7	91·75
83	91·8	91·9	91·9	92·0	92·0	92·1	92·15	92·2	92·3	92·3
84	92·4	92·4	92·5	92·55	92·6	92·7	92·7	92·8	92·8	92·9
85	92·9	93·0	93·05	93·1	93·2	93·2	93·3	93·3	93·4	93·4
86	93·5	93·5	93·6	93·6	93·75	93·75	93·8	93·9	93·9	94·0
87	94·0	94·1	94·1	94·2	94·2	94·3	94·3	94·4	94·4	94·5
88	94·55	94·6	94·65	94·7	94·75	94·8	94·85	94·9	94·95	95·0
89	95·05	95·1	95·15	95·2	95·25	95·3	95·35	95·4	95·45	95·5
90	95·5	95·6	95·65	95·7	95·75	95·8	95·85	95·9	95·95	96·0
91	96·0	96·1	96·1	96·2	96·2	96·3	96·3	96·4	96·4	96·5
92	96·5	96·6	96·6	96·65	96·7	96·75	96·8	96·85	96·9	96·95
93	97·0	97·0	97·1	97·1	97·2	97·2	97·3	97·3	97·35	97·45

RECORD A.

IMPORTS.

	CANES.	JUICE.						
	Tons.	Gallons.	Tons.	Per cent. Juice on Canes.	Brix.	Sucrose. Pounds per Gallon.	Purity.	Indicated Sugar Pounds
June 4.. ..	298·5	40600	194·1	65·0	18·0	1·533	79·5	62240
,, 5.. ..	263·3	36110	172·2	65·4	17·4	1·496	80·5	54021
,, 6.. ..	283·7	38241	182·1	64·2	17·1	1·468	80·5	56138
,, 7.. ..	257·6	34484	164·6	63·9	17·7	1·485	78·5	51209
,, 8.. ..	279·1	37826	180·9	64·8	18·2	1·519	77·9	57458
,, 9.. ..	290·8	39803	189·9	65·3	17·6	1·479	78·6	58869
								339935 =
This week ..	1673·0	227064	1083·8	64·8	17·65	1·497	79·3	151·7 tons
Previously ..	8234·7	1110207	5286·7	64·2	17·10	1·458	79·9	722·6 ,,
To Date ..	9907·7	1337271	6370·5	64·3	17·18	1·464	79·9	874·3 ,,

RECORD B.

Exports.

	I. Sugar.					II. Sugar.		Molasses.	
	Tons.	Polarization.	Per Cent. on			Tons.	Polarization.	Tons.	Polarization.
			Canes.	Massecuite.	Indicated Sugar.				
Monday									
Tuesday									
Wednesday..									
Thursday ..									
Friday......									
Saturday....									
Monday									
This week ..									
Previously ..									
To Date									

RECORD C.

Exports for Crop..........

	Commercial Sugar.	Containing Pure Sucrose.	Commercial Sugar Polarization.	Per cent. of Commercial Sugar on				Pure Sucrose recovered per cent. on	
				Canes.	Massecuite.	Indicated Sugar.	Available Sugar	Indicated Sugar.	Available Sugar.
I. Sugar ..									
II. ,, ..									
III. ,, ..									
All Sugars ..									

The Laboratory Records.

The results we have been considering are conveniently recorded, as shown on the adjacent pages.

The weekly imports of canes, juice, and indicated sugar are added to the amounts carried forward from previous weeks yielding totals *to date;* the latter being then carried forward to the next week's record.

The weekly averages for *Percentage of Juice, Brix, Sucrose,* and *Purity* can rarely be obtained by averaging those recorded for the six days because the quantities of cane and juice treated per day are variable. These are therefore calculated from the totals of the three other columns in the manner shown below.

Percentage of Juice on Canes. This is obvious, but we give the figures :—

	Canes Tons.		Juice Tons.
This week	1673	yield	1083·8
„	100	„	64·8
To date	9907·7	„	6370·5
„	100	„	64·3

Brix. By a reverse use of Table I. (page 41) we may arrive at the degrees Brix when the volume and weight of juice are known, thus :—

$$\frac{\text{Weight of juice in pounds}}{\text{Volume of juice in gallons}} = \text{weight in pounds of one gallon.}$$

from which corresponding degrees Brix may be found in the Table. But, as the weight of juice is more conveniently recorded in tons, the calculation becomes :—

$$\frac{\text{Weight of juice in tons}}{\text{Gallons of juice} \div 2240} = \text{weight in pounds of one gallon.}$$

$$\textit{This week}\ \frac{1083{\cdot}8}{227064 \div 2240} = \frac{1083{\cdot}8}{101{\cdot}4} = 10{\cdot}691 = 17{\cdot}65 \text{ Brix.}$$

$$\textit{To date}\ \frac{6370{\cdot}5}{1337271 \div 2240} = \frac{6370{\cdot}5}{597} = 10{\cdot}671 = 17{\cdot}18 \text{ Brix.}$$

NOTE.—It is preferable to state the degrees Brix to two decimals in order to obtain correct figures for the Purity (see under).

SUCROSE. The *indicated sugar* being the product obtained on multiplying *gallons of juice* by *pounds sucrose per gallon*, it is obvious that the last may be calculated from the two former, thus :—

$$\frac{\text{Pounds indicated sugar}}{\text{Gallons of juice.}} = \text{pounds sucrose per gallon.}$$

But here, again, we avoid large figures by recording the indicated sugar in tons, so that the calculation becomes :—

$$\frac{\text{Tons indicated sugar}}{\text{Gallons} \div 2240} = \text{pounds sucrose per gallon.}$$

$$\textit{This week}\ \frac{151{\cdot}7}{227064 \div 2240} = \frac{151{\cdot}7}{101{\cdot}4} = 1{\cdot}497.$$

$$\textit{To date}\ \frac{874{\cdot}3}{1337271 \div 2240} = \frac{874{\cdot}3}{597} = 1{\cdot}464.$$

It will be seen that the divisor is the same as that employed above for finding the *Brix*.

PURITY. This is calculated from the *Brix* and *sucrose per gallon* as explained on page 79.

This week, 17·65 Brix = 10·691 lbs. juice per gallon—

$$\frac{1{\cdot}497 \times 100}{10{\cdot}691} = 14{\cdot}002 \text{ sucrose per cent. by weight.}$$

$$\text{and } \frac{14{\cdot}002 \times 100}{17{\cdot}65} = 79{\cdot}3 \text{ purity.}$$

To date, 17·18 Brix = 10·671 lbs. juice per gallon.

$$\frac{1{\cdot}464 \times 100}{10{\cdot}671} = 13{\cdot}719 \text{ sucrose per cent. by weight.}$$

$$\text{and } \frac{13{\cdot}719 \times 100}{17{\cdot}18} = 79{\cdot}9 \text{ purity.}$$

The general practice in chemical control is to divide the manufacturing season into weekly periods, and, at the close of each week, to account for the imports of indicated sugar by the produce actually bagged off and the probable yield of produce from the syrup and masse-cuite still on hand. Whilst this course is desirable, the figures obtained can only be accepted as provisional and subject to correction when the last of the sugar has been weighed.

What can be done in the direction of a weekly balance sheet is to record the percentage of I. Sugar on the weight of canes ground, and also on the indicated sugar in the juice, thereby keeping a check on the largest of the factory exports. It is only necessary to arrange that the I. Massecuite, left in hand on Saturday night, shall be cured separately from that made from the following week's juice. Record B. is arranged on these lines, and may include a record of the II. Sugar and Molasses exported during the same period (but belonging to an earlier one.)

At the close of the manufacturing season the percentages of exports on imports may be summarized as shown in Record C., to which further reference will be made.

CHAPTER XII.

THE CONTROL OF THE EXPORTS.

As the exports are closely connected with the subject of the last chapter, they will be conveniently considered next.

In the case of *grocery sugars*, appearance is the all important consideration. Colour may, of course, be roughly measured, as in the case of the old " Dutch Standards," but a more satisfactory test is to compare the colour, turbidity, etc. of solutions of the sample and the standard, prepared under identical conditions and examined in similar vessels. Apart from colour, the sparkling appearance of high-grade sugars is due to the regular shape of the individual crystals, and can only be secured by careful working of the syrup and masse-cuite in the pan. The regularity of the crystals is easily observed with the aid of a magnifying glass, and if the sugar cured from different strikes of masse-cuite be thus examined and compared, the pan-boiler may be promptly called to account for inferior work.

The polarization test is now generally adopted for fixing the import duty paid by the sugar producer, or his agent, but in the case of *refining sugars* this test also serves as a basis for the selling price, so that in such instances, the polariscope plays an important part in commerce. But as the producer generally sells through an agent he is not called upon to certify the purity of his produce ; indeed, his certificate would have no weight with the Customs' officials who apply this test at the receiving port. Yet, it is none the less desirable to know the polarization of refining sugar as it leaves the factory in order that, by careful attention to the curing of same, the polarization may be as near as possible to the standards accepted by the Customs, and the duty thus minimised. Occasionally, the manufacturer is required to supply crystals of a given polarization, and the optical test then becomes essential.

Here, however, we shall employ the test with a very different object, namely, to account for the sugar originally present in the juice. As the weight of crystallized produce obtained does not represent pure sucrose, it becomes necessary to bring the polariscope to bear on the exports as well as on the imports. For example, 100 tons of crystals polarizing 96·0, represent only 96 tons of pure sucrose, since the remaining 4 tons consist of impurities and count for nothing. This difference between commercial " sugar " and pure sucrose will necessarily be greater in the case of low-grade produce. To convert tons of commercial sugar into tons of pure sucrose it is therefore necessary to multiply by the polarization and divide the result by 100.

This being done for each grade of sugar made, we arrive at the output of pure sucrose, which can be expressed as a percentage of either the *indicated* sucrose, or of the *available* sucrose in the juice (see the second, eighth, and ninth columns of Record C.). It being, however, still customary to express these percentages in terms of commercial sugars, these higher results would appear under the sixth and seventh columns of the Record.

SAMPLING.

As in the case of the juice, the object here is to secure a single sample representing the day's output. The most satisfactory plan is for the sugar weigher to abstract a small measureful from every bag filled, emptying the measure into a dry keg, or other receptacle. At the end of the day the contents of the keg are emptied out, thoroughly mixed, and a measureful removed to serve as a laboratory sample. If there is not sufficient time to test the sugar every day, a *weekly sample* may be collected by storing one measureful, taken from the keg every day, in a closed vessel, from which a final sub-sample is drawn at the end of the week.

Such average samples being required for statistical purposes, additional samples will be required from time to time in order to learn whether the sugar is being properly cured. Such samples are preferably taken from the sugar-elevator in order that they may represent the mixed product of several machines *treating the same masse-cuite.* Another reason for this is that the " wall " of cured sugar in any one machine in not uniformly cured, and cannot be thoroughly mixed until discharged from the basket. If the latter discharges on to a tray (instead of on to a conveyor) the contents of the tray may be mixed and a sample taken therefrom.

Occasionally, it is also necessary to sample a large heap of sugar before this is bagged off. If a sampling tube be not available, it is necessary to cut away one side of the heap so as to expose a section of the whole. Handfuls of sugar are then removed at different heights, mixed together, and a sub-sample taken for analysis.

THE OPTICAL TEST.

The laboratory sample is carefully mixed before the "normal polariscope weight" of same is weighed into the counterpoised basin. This is dissolved and transferred to the 100 c.c. measure flask, as directed in Chapter VI; the solution being clarified by the addition of basic actate of lead before diluting same to 100 c.c. In the case of sugars polarizing about 96, 2 c.c. of lead solution is ample, but this should be increased to 5 c.c. in the case of low grade and muscovado sugars.

After being mixed and filtered, the solution is "*polarized*" in the 200 m.m. tube; the scale-reading (corrected for zero) giving the polarization or the *percentage by weight* of sucrose in the sample tested.

CHAPTER XIII.

DETECTION OF AVOIDABLE LOSSES.

The factory chemist is usually called upon to account for the whole of the indicated sugar entering the factory, but as this work is beset with difficulties and occupies much time, we shall here substitute some simple tests which can be carried out by those who have other duties to attend to.

The loss of sugar in the megass having been already dealt with, we proceed to the following—

(*a*) THE LOSS OF SUGAR IN THE FILTER-PRESS CAKE.

With modern presses, the loss of sugar in the cakes should not exceed 4 per cent. on the indicated ; the cake itself containing from 7 to 10 per cent. of sugar. A sample is secured by breaking off small fragments from several cakes and crushing these to a coarse powder in the wedgewood mortar. Fifty grams of this powder is weighed into the metal basin, transferred to the empty and clean mortar, and rubbed up with sufficient water to form a cream. The latter is then poured through a funnel resting in the neck of a 200/220 c.c. measure flask. The residue in the mortar and that adhering to the pestle is rinsed into the flask with small additions of water, 10 c.c. of basic acetate of lead added, and the contents of the flask diluted exactly to the lower (200 c.c.) mark. After thorough mixing, the liquid is filtered and the filtrate polarized ; the reading of the scale gives the percentage of sugar in the sample examined. It will be noted that in this case 50 grams of sample have been diluted to 200 c.c. (25 grams to 100 c.c.) instead of the normal weight of 26·048 per 100 c.c. This is done to avoid a correction for the volume occupied by the insoluble matter, of which the sample contains about 40 per cent.

A knowledge of the sugar-content of the cake is not of much interest unless it is desired to calculate the loss of sugar from the gross weight of cakes discharged from the factory. If the cakes are firm and brittle an analysis is generally superfluous, so that it is well only to test samples when the work appears to be at fault.

(*b*) LOSS OF SUGAR DUE TO DEFECTIVE PAN-BOILING.

A loss of first product, even though recovered in the form of second and third products, is clearly a loss in value, and is due to two defects in the pan work :—

1. Incomplete boiling, whereby too much sugar is retained in solution in the fluid portion of the masse-cuite.

2. Irregular boiling, resulting in the formation of crystals of various sizes, and loss of the smaller crystals which are carried through the centrifugal liners by the molasses.

In order to detect this loss of first product we propose to ascertain experimentally what percentage of cured sugar is obtained from each strike of syrup masse-cuite.

THE MASSE-CUITE TEST.

The weight of masse-cuite used in the test is determined by the size of the centrifugal baskets, the object being to cure a weighed quantity of masse-cuite under ordinary working conditions. A basket, 30in. in diameter (the most general size), has a working capacity of 3 cubic feet, and as this volume of masse-cuite weighs about 250 lbs., the charge is conveyed from the pan to the sugar-scale, and thence to the centrifugals, in three wooden boxes, constructed of 1 inch board with screwed joints, and measuring internally a foot every way. Each box is provided with two pairs of handles formed by horizontal pieces bolted to opposite sides of the box and projecting a foot or more at either end of same.

As the masse-cuite flows from the pan, small portions of the strike are caught on a spade and transferred to the boxes, the sampling being so timed that the first box is full when about one-third of the strike has been discharged, and the other boxes filled at the same rate. In this manner it is easy to collect three cubic feet of masse-cuite which will accurately represent the bulk of the strike, even though the contents of the pan were not uniformly mixed.

The filled boxes are piled, one above the other, upon the platform of the sugar scale, and the gross weight accurately noted. The contents are then transferred to a centrifugal basket, and the empty boxes re-weighed to find the tare. The experimental charge is cured without the use of water or steam ; being spun, say, ten minutes. A small sample of the molasses, caught direct from the outlet of the centrifugal, should be reserved for the "Molasses Test" (see below). The cured sugar is finally discharged upon a tared tray and weighed, as in the following example:—

$$\frac{\text{Net weight of cured sugar} = 171 \text{ pounds.}}{\text{,,}\quad\text{,,}\quad \text{masse-cuite} = 260 \text{ pounds.}} \times 100 = 65{\cdot}8\%.$$

This may be taken as a fair average result, but as the percentage fluctuates according to the purity of the masse-cuite, this should be ascertained by proceeding as follows.

Before weighing the three boxes, a few ounces of masse-cuite are removed from each and thoroughly mixed. About three ounces of this mixed sample (actual weighing is not necessary) are placed in a wide-mouthed stoppered bottle,* and as much rain-water added as will fill one of the jars used for testing densities. The bottle is then vigorously shaken at intervals until every trace of masse-cuite is dissolved, and the density of the solution observed by means of the Brix hydrometer. If this falls within the limits, 15·0–20·0, the degree of dilution is sufficient. If above 20·0 a little water must be added; or if below 15 a little more masse-cuite must be dissolved in the original liquid. This solution of masse-cuite is analysed in precisely the same way as the juice; the purity being calculated from the density and per cent. by weight of sucrose.

This "Curing Test" can only be applied to low grade masse-cuites which have been crystallized in motion. In the usual form of crystallizing tank a partial separation of sugar takes place, so that it is practically impossible to secure a representative sample of the contents.

In order, then, to control the later stages of the pan work we must examine the final molasses, and satisfy ourselves that it contains the minimum of dissolved sugar. If the first and final stages of the boiling pass muster, the yield obtained in the intermediate stage or stages will also have been satisfactory.

How much sugar the final molasses should contain depends on the purity of the juice, or, more correctly, on the nature of the impurities present, some of which tend to keep the sugar from crystallizing, and are therefore known as *molasses-formers*. But, instead of examining these impurities, which would entail rather intricate methods of analysis, we can arrive at the desired information by means of another experiment.

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* One of those used for preserving samples of juice.

If the syrup masse-cuite be cured hot (the most general practice) the molasses escaping from the centrifugal will be a super-saturated solution of sugar ; that is, a solution from which sugar will crystallize out on cooling. Such molasses also invariably contain a quantity of small crystals, which re-dissolve during re-boiling of the molasses, and re-appear on cooling as second or third sugars. Consequently, if what is called *first* molasses could be completely deprived of crystals the remaining fluid would be *true* molasses, containing the minimum quantity of dissolved sugar. We propose to remove these crystals by filtering the *cold* molasses through a strainer of a much finer texture than that employed in the centrifugals.

THE MOLASSES TEST.

This is carried out on the sample of molasses reserved from the *masse-cuite test*, but time and labour can be economised by mixing together many samples of molasses, and carrying out the test at the end of the week.

Assuming that every strike of syrup-masse-cuite is tested as directed above, it will be sufficient to reserve one test-tubeful of molasses from each experiment, storing these together in a tin canister capable of holding about two pints, and provided with a lid. The contents of the canister must be thoroughly mixed every time a sample of molasses is added, as stirring promotes crystallization. At the end of the week the canister will be more or less filled with *cold* molasses, but in order to allow time for the later additions to become fully crystallized, the next operation of filtration may be delayed until the following week. Even with this delay the result will be obtained many days in advance of the slow operations in the factory where the same molasses are being boiled and re-boiled at long intervals.

The filter is made of closely woven brass wire, having 100 meshes to the lineal inch.* A square piece, measuring 12 inches on each side is folded in exactly the same manner as a filter paper but making only four folds in all. The four corners of the square may be cut away with a pair of shears, so that the piece of gauze is rendered circular when opened out. In doing this, the folds must not, of course, be obliterated ; but, by careful handling, the gauze is given a form similar to that shown in *Fig.* 10, and inserted in a large glass funnel. To render the filter effective, every trace of grease is removed by immersing the gauze in a strong solution of caustic soda, and then in several changes of clean water. Whilst still wet the

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*See Appendix.

filter is placed in the funnel, the latter being supported in the wooden ring of the filter stand instead of the arrangement shown in *Fig.* 11.

The sample of molasses is transferred to the filter gauze until the latter is quite full, a small cylinder being placed under the funnel and the latter covered with a ground-glass plate.

In spite of the fine mesh of the gauze, the first portions of filtrate contain many minute crystals which can be seen on spreading a drop or two upon a piece of glass and holding this in front of a strong light ; the appearance being much the same as that of syrup at the "graining point." The first ounce of filtrate is therefore rejected and the remainder collected in a 100-110 c.c. measure flask, which has been previously allowed to drain dry and accurately weighed. The support holding the funnel should be raised or lowered so as to cause the stem of the funnel to just enter the neck of the flask (if the former be not too wide).

Thus arranged, the apparatus must be left to itself until sufficient material is collected for analysis. As the filtration proceeds very slowly, we save time (and material) by collecting the filtered molasses in the weighed measure flask, the latter serving as a substitute for the counterpoised basin. The half-normal weight (13·024 grams.) is added to the tare of the empty flask on the right-hand pan of the balance, and as soon as the flask contains sufficient molasses to turn the scale, a small quantity of the latter may be removed by means of a glass rod ; the adjustment being continued until the index-pointer of the balance swings to equal distances on either side of the zero.

Some rain-water (previously heated to boiling in a test tube) is added to the flask, and the latter gently shaken from side to side until the molasses are completely dissolved, after which it is cooled by immersion in cold water. Ten c.c. of lead solution are run in from a pipette and, finally, as much water as will dilute the whole exactly to the lower mark (100 c.c.). After mixing, the solution is filtered and polarized as in the analysis of juice and sugar. The mean of five readings multiplied by two gives the percentage of sucrose by weight.

The final molasses obtained in the factory can also be sampled daily, and analysed once a week. It is rarely quite free from crystals, but these should not be removed by filtration as they constitute part of the actual loss of sugar to be detected. As there is plenty of this material for analysis, it is weighed into the counterpoised metal basin, and dissolved therein by stirring with cold water; the half-normal weight being taken as before, and the same amount of lead solution. This simple method of analysis is not very accurate when applied to such impure material as molasses, but provided that the test is applied in both cases under the same conditions, the figures obtained will be strictly comparative, and therefore of practical value.

On comparing the sugar content of the *filtered* molasses prepared in the laboratory, with that of the final molasses obtained in the factory, a close agreement must not be expected although the differences should not be great. The liming of molasses before or during re-boiling has some effect on the subsequent crystallization, and it is also necessary to compare molasses of the same origin (*i.e.*, derived from the same first molasses). By averaging the analytical results obtained during the whole crop season, a much more satisfactory comparison can be made.

(*c*) Losses of Sugar during Curing.

These are mainly due to the excessive use of water (or steam) for purging the sugar, and can only be partially avoided in the manufacture of white crystals. A few experiments should be made in which baskets charged with the same masse-cuite are spun for a given time with diminishing quantities of purging water (or shorter applications of steam), and the resulting sugars polarized and their colours compared. In the case of refining crystals, the use of water or steam in the centrifugals should be dispensed with entirely.

CHAPTER XIV.

THE CONTROL OF THE FUEL.

To run a sugar factory on economic lines, it is not sufficient to recover the maximum quantity of sugar, but to do this at the lowest possible cost both in labour and material, including that important item—fuel.

Now, on this score, the cane industry has an enormous advantage over that of the beet, since the crushed cane, or megass, is a fuel which costs nothing, and is already on the spot. With modern boilers and specially designed furnaces no other fuel is required ; indeed, the problem is rather how to dispose of the surplus megass, or to utilize the surplus steam when the whole of the megass is sent to the furnaces.

That a cane sugar factory can entirely dispense with a fuel account is not sufficiently recognized, judging from the number of factories where wood, or even coal is burned in addition to the megass, or where the furnaces are of so antiquated a type that the megass has to be sun-dried before it can be used as fuel. When the wages paid for cutting and transporting wood, or for sun-drying the megass, are recorded as "fuel," it is found that steam is frequently a costly item of the working expenses.

First, then, as regards the megass. If sun-drying has to be resorted to, it is important to know when the proper degree of dryness has been obtained so that labour may be economized. An experienced stoker may be able to distinguish between well dried and badly dried megass by the sense of touch, but if we would control his work we must have an independent check, free from all errors of judgment.

Such a check we have in the *Megass Test*, described in Chapter IX. Five pounds of sun-dried megass will be sufficient to fill one of the wire cages, and the drying operation should be complete in from two to three hours. Care must be taken to secure samples representing equal parts of the upper and lower layers, and taken from different spots in the factory yard. If the sun-drying has been sufficient, the loss in weight should not exceed 15 per cent., that is ¾lb. on the 5lbs. of megass tested.

As regards the fuel-value of ordinary "wet" megass, no very exact data are available. One ton of good Scotch coal is equivalent to from three and a half to four tons of megass from a double-crushing mill, and to four or five tons of single-crushed megass.

In factories burning coal, the first step towards economy is to know that the quality of the coal supplied is proportional to the price paid for it ; the second step being to see that the heating value of the coal is utilized to the best effect by skilful stoking.

Whenever practicable, a sample taken from each shipment of coal should be submitted to an analyst, who will report on the heating value and percentage of ash for a moderate fee. When such advice is not available, the heating value may be determined in the factory laboratory by means of an apparatus called a Calorimeter (*i.e.* heat measurer). This is a device for burning a weighed quantity of coal in such a manner that the whole of the heat evolved is absorbed by a large volume of water, the rise in temperature of which is very accurately measured. In either case, the first step is to secure an average sample of coal from the bulk.

SAMPLING.

A few lumps of average size,, are taken from each truck—or punt-load— and broken into small pieces by means of a hammer upon a clean concrete floor. The large sample, thus obtained is then mixed by shovelling the outlying fragments towards the centre of the heap until the latter assumes the form of a cone with circular base. This operation is next reversed by raking the coal from the centre of the heap towards the circumference, repeating this all round until a layer of uniform depth is secured. A straight-edge of wood, or metal, is pressed down upon the sample in such a manner as to divide the heap into two equal portions, which can then be slightly separated by pushing the straight edge laterally. A similiar dividing line is then made at right angles to the first, by which means the whole sample is divided into quarters. Alternate quarters are then removed, together with the fine dust belonging to them, and the remaining quarters re-mixed to form a smaller cone which is flattened out, quartered, and two alternate quarters removed as before. In this manner the sample can be greatly reduced in bulk, whilst still fairly representing the original sample. When only about ten pounds remain, this residue must be crushed to a coarse powder in an iron mortar before the "quartering" can be carried further. The powdered coal, after mixing, is spread out upon a large sheet of paper and repeatedly "quartered" until a sample weighing about one pound is obtained.

The above operations may appear unnecessarily tedious, but in the absence of special apparatus no simpler method of sampling can be relied upon.

THE COAL TEST.

Printed instructions for using the Calorimeter are supplied with the apparatus, but these being somewhat condensed we will attempt to simplify this very interesting test, commencing with a few words of *Theory*. Measurements of various kinds can only be expressed in terms of some arbitrary unit; for example, the inch, the gallon, the pound, etc. In the case of heat, it is very necessary to distinguish between *quantity of heat* and *temperature*, since the same quantity of heat produces different temperatures when applied to different substances. But to raise the temperature of a gallon of water from, say, 60° to 61°F., always requires the same *quantity of heat* and thus affords a basis of measurement.

The metrical system of weights and measures being most convenient in scientific work, the unit now universally adopted is the quantity of heat required to raise the temperature of one kilogram of water one degree Centigrade. Adopting this unit, which is known as a *calorie*, the heating power, or calorific value, of fuels can be conveniently expressed in terms of the number of calories developed on burning one kilogram of fuel.

The Calorimeter is designed to burn only two grams of coal, the heat evolved being absorbed by two kilograms of water. For each degree Centigrade that the temperature of this water is raised, two calories will have been set free by the combustion of the coal, there being two kilograms of water heated instead of one (see definition given above). Again, as only two grams of coal are used in the test, the quantity of heat measured must be multiplied by 500 to obtain the heating effect of a kilogram (1000 grams of coal). Consequently the number of degrees Centigrade through which the two kilograms of water are heated must be multiplied by 2×500, or 1000, in order to arrive at the true calorific value of the coal tested.

THE APPARATUS comprises five parts :—

1. A metal cylinder, terminating above in a metal tube with tap, and having a double row of perforations below.

2. A circular metal base, to which the said metal cylinder can be attached by means of springs.

3. A metal tube, or cartridge, to hold the combustibles, and which can be fixed vertically in the centre of the metal base. Cartridges of two sizes are supplied with the apparatus ; the shorter tube being alone used for testing coal.

4. A large glass cylinder in which the above apparatus can be immersed in water.

5. A delicate thermometer graduated in tenths of a degree C.

INSTRUCTIONS.—It being desirable to know the temperatures of the laboratory, the thermometer may be left exposed on the table whilst the following preparations are made.

The one-pound sample must be re-ground in the iron mortar until the whole can be passed through the metal sieve. Two grams of this fine dust are carefully weighed into the counterpoised metal basin and then emptied into the wedgewood mortar ; the latter having been previously heated for about half an hour in the megass drying-chamber. It is once again ground up with the pestle, the heat of the mortar serving, at the same time, to remove any traces of moisture. To it are added twenty-six grams of oxygen mixture,* and the two powders mixed by grinding until the mixture assumes a uniform grey colour.

This mixture has next to be transferred, without loss, to one of the short metal cartridges in the following manner. :—

The mortar and cartridge (the latter upright) are placed side by side on a sheet of smooth writing-paper. By aid of the steel spatula the mixture is then transferred from the mortar to the cartridge in small quantities, tapping the base of the cartridge upon the table after each addition in order to compress the charge and thus render its combustion rapid and uniform.

During these manipulations any accidental spillings should fall upon the paper placed to receive them and to these are added the

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* A tin of this is supplied, but fresh quantities may be prepared by mixing three parts of powdered Potassium Chlorate and one part of powdered Potassium Nitrate (common Nitre). This mixture which must be kept absolutely dry, supplies the oxygen required for the combustion of the coal, since for the purpose of the test, the coal must be burnt out of contact with air.

last traces of mixture from the mortar by dusting out the latter with a camel hair brush. Folding the paper almost double, the last of the mixture is easily brushed direct into the metal cartridge, which should now be quite full. If there appears more of the mixture than the cartridge will hold, it is because the charges have not been sufficiently compressed, in which case the remedy is obvious.

To fire the charge the cartridge must finally be fitted with a fuse, prepared by soaking lamp-cotton in a strong solution of nitre, and drying. A length of about an inch is sufficient, a quarter of which is pushed into the charge leaving three-quarters of an inch protruding. The cartridge is then inserted in the metal base and covered by the metal cylinder, the tap on which is closed.

After observing the air temperature of the laboratory, a bucketful of cold water is procured and its temperature also observed. If a few degrees Centigrade below the air temperature, so much the better ; but, if not, a lump of ice should be added until the temperature falls 7°C. below that of the air. After removing the ice, the water is poured into the large glass cylinder to the level of the 2000° c.c. mark on same, which is the volume occupied by two kilograms of water. Holding the metal apparatus just above the tap, lower same into the cylinder until it rests at the bottom with only the tap projecting above the surface of the water. In this position, the metal cylinder remains full of air so long as the tap is closed, and there is no risk of the enclosed charge being wetted.

The thermometer is suspended from the rim of the glass cylinder by means of a bent wire hook in such a position that the thermometer bulb is midway between the top and bottom of the glass cylinder The scale of the thermometer should be clearly visible through the side of the glass vessel, so that the temperature may be read off without removing the thermometer from its position.

The metal work and glass soon acquire the temperature of the water, but it is necessary to stir the latter by gently raising and lowering the metal apparatus until the thermometer gives a constant reading.

The metal apparatus is now removed from the water, the cylinder separated from the base, and the free extremity of the fuse ignited. The apparatus is then quickly put together again and re-immersed in the water.

In less than a minute a rapid flow of gas bubbles escape from the perforated base of the cylinder, showing that the charge has ignited. As these bubbles rise through the water a rapid interchange of heat takes place, the cold water being warmed, and the hot gases cooled. As soon as the action quite ceases, the tap is opened so as to allow water to enter the apparatus.

The water is then once more thoroughly stirred by raising and lowering the metal apparatus, whilst the eyes are kept on the thermometer. The mercury column will be seen to rise steadily, and as soon as it remains stationary the reading is noted down. Both the initial and final temperatures must be read off to a tenth of one degree.

The difference between the initial and final temperatures, multiplied by 1000, should give the Calorific value of the sample of coal tested, but a correction of one-tenth is added for the heat absorbed by the metal apparatus itself.

The following example will make this clear :——

		Degrees Centigrade.
Temperature of Room	=	19·3
Temperature of water before combustion ..	=	13·2
Temperature of water after combustion ..	=	20·3
Increase in temperature of water:—20·3—13·2	=	7·10
Heat absorbed by Calorimeter = 1/10th ..	=	·71
Corrected rise in temperature	=	7·81

7·81 × 1000 = 7810 Calories.

From this result we can calculate the evaporating power of the fuel ; this being usually expressed as pounds of water (at the boiling point) converted into steam at the same temperature. This is done by dividing the total Calories by 537 ; and in our example we obtain $\frac{7810}{537} = 14{\cdot}54$ pounds of water evaporated per pound of coal, from and at 100°C. (212°F.)

NOTE.—To obtain correct results by this test, it is of course assumed that the two grams of coal are completely burned, leaving only a small quantity of grey ash free from black particles. To make matters certain, the metal apparatus should be removed from the water and the latter allowed to stand undisturbed for some hours so that the suspended ash (and coal, if any) may settle to the bottom of the glass cylinder. On separating the metal cylinder and base, the cartridge will be found full of water, which should be emptied into a clean test-tube, and the cartridge rinsed out with small additions of clean water, these rinsings being added to the test-tube which is then allowed to stand. The sediments left in the large glass cylinder, as also that in the test-tube, should be examined after decanting off the bulk of the clear water. If dark in colour, some carbon in the two grams of coal will have escaped combustion and the result of the test will be slightly below the actual calorific value. A correction for any unburned carbon is possible, but somewhat difficult to carry out, and it is therefore better to ensure complete combustion by taking the following precautions.

1. Dry about 30 grams of the oxygen mixture before weighing out the 26 grams used in the test. This may be done by exposing same in a thin layer to the air in a heated place.

2. The two grams of coal must be very finely divided and perfectly mixed with the 26 grams of oxygen mixture.

3. The metal cartridge must be absolutely dry, and the charge uniformly compressed.

It may be added that the Calorimeter described above is quite unsuitable for ascertaining the calorific value of megass.

Next in importance to the *quality* of the coal comes the *quantity* required to make a ton of sugar. Even the stoking of the furnaces can be brought under chemical control by analysing the flue gases, but the methods are too refined to bear simplification. Considerable economy may, however, be effected by a judicious use of a "coal weigher" in distributing the fuel to the furnaces, and by noting which stokers use the most coal.

APPENDIX

The apparatus and chemicals mentioned in this book may be obtained from Messrs. Townson & Mercer, 34 Camomile Street, London, E.C., by forwarding them a copy of the list which follows.

The outfit, packed in case for export, costs about £50, and includes such spares as may be required from time to time. The last three items, being only required for testing coal, may be omitted in many cases.

NOTE.—The marginal numbers 1, 2, and 3, refer to the following firms, who will supply the items so marked through Messrs. Townson & Mercer :—

1. Franz Schmidt & Haensch, Berlin.
2. Keppeller, Vienna.
3. Messrs. Bryan, Corcoran, Ltd., 31 Mark Lane, E.C.

		£	s.	d.
1.	One polariscope, half-shadow, single compensation, for 200 m.m. with 100 and 200 m.m. tubes, complete in box..	21	0	0
	One extra metal tube, 200 m.m., old pattern	1	0	0
	One dozen cover plates, for above	0	3	6
	Two dozen rubber washers, for above..	0	1	2
	One normal quartz plate mounted in brass tube for adjusting Polariscope to read 100° Ventzke with table showing values from 10° to 35°C.	1	10	0
	One polariscope lamp, adjustable, metal chimney, etc., for petroleum	1	3	6
	Ten yards wick for above	0	1	8
	Two spare lenses and two spare reflectors, for above	0	5	0
	Nine flasks, graduated in Mohr's Units, at 17½C., three each of :—			
	50 to 55 c.c.	0	4	0
	100 to 110 c.c.	0	4	10
	200 to 220 c.c.	0	7	4

		£	s.	d.
2.	Six Balling hydrometers, graduated at 85°F. from 12° to 20° Balling in tenths of 1°, each tenth being about one-sixteenth of an inch, flat stem, total length of stem about 5in., of bulb 4in., diameter of bulb from ¾in. to 1in.	2	14	0
3	One Salter's spring balance, No. 60, to weigh 20 lbs. by half ounces, with hook attachment only, and two 12in. brackets	1	2	6
	20ft. woven fine wire, No. 7, 3ft. wide	1	0	0
	3lbs. lacing wire, 22 gauge	0	1	0
	2ft. woven brass wire, 100 meshes to lineal inch, 2ft. wide = 4 square feet	0	14	0
	One Beckers balance, in case, agate knives and planes, to carry 100 grams in each pan, sensitive to 1mg., without rider apparatus	3	2	6
	One set of weights, 100 grams to 1 mg., with forceps in box with lid	0	12	6
	One spare set of Becker's aluminium weights :—5, 2, 2, 1 mg.	0	1	3
	One German silver basin, with lip and flat bottom, and counterpoise weight	0	4	6
	Two spatulas, bone, 8in. long	0	1	6
	Three hydrometer jars, with lip, 10in. × 1⅝in.	0	2	0
	Six ,, ,, ,, 6in. × 1¼in.	0	2	6
	Six funnels, plain, ground edges, 4in. diameter	0	1	9
	Three ,, ,, ,, 7½in. ,,	0	4	6
	Twelve ground glass covers, 5 in. diameter	0	0	6
	Six ,, ,, 8in. ,,	0	1	6
	One filter stand, black wood, for two 7½in. funnels	0	4	2
	Three graduated cylinders, on foot, with lip, 10c.c. in tenths c.c.	0	2	0
	Two Test Mixers, on foot, with lip, 50c.c., 100 divisions	0	2	0
	Three pipettes, 10c.c. graduated in tenths c.c.	0	2	6
	Two pipettes, 10c.c., with bulb at end one	0	0	6
	Twelve packets of 100 circular filter papers, Muncktell's No. 1 F., 15 c.m. (6in.) diameter	0	15	0
	Six bottles, W.M. green glass, stoppered, one pint capacity	0	3	3
	,, N.M. white glass, flat stoppers, 6 oz.	0	1	9
	Two dropping bottles, with slotted stopper, A.K. patent 100 c.c. capacity.	0	0	8

	£	s.	d.
One gross test tubes, 4in. × $\frac{5}{8}$in.	0	3	0
Six test tube brushes	0	0	6
One ,, holder	0	0	6
One test tube stand, with 12 holes and draining pegs	0	3	0
Two dozen books of neutral litmus paper	0	3	6
Six books of red litmus paper	0	1	0
,, .. blue ,, ,,	0	1	0
One yard black rubber tubing, $\frac{1}{2}$in. internal diameter	0	3	9
Two thermometers, 240 F. enclosed paper scale, cylindrical bulb	0	2	6
One spirit lamp, glass, 8 oz. capacity	0	0	10
One mortar and pestle, wedgewood, 5in. diameter	0	2	3
Two Winchester quarts basic acetate of lead	1	2	8
1 oz mercuric bichloride	0	0	6
1 lb. sugar, chemically pure (Tate's cubes)	0	0	6
One dozen glass rods, fused ends, 5in. long, $\frac{3}{16}$in. thick	0	0	4
Triangular file, 4in. long	0	0	4
Two foolscap note books	0	1	0
Six glass-cloths, or dusters	0	2	0
One calorimeter, Thompson's, for testing coal, complete in box	5	10	0
One spare glass cylinder, for above	0	7	6
One spare thermometer, ,,	0	12	6
Packed in case for export	£46	0	0

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