ART. XVIII.—*On certain Lecture Experiments, and on a new form of Eudiometer*; by JOSIAH P. COOKE, Jr.

THE laws of combination by volume fill such an important place in our modern chemical philosophy that simple methods of illustrating these fundamental principles in the lecture room are eagerly sought by every teacher of the science. The many new and interesting experiments devised for this purpose by Prof. Hofmann, first described in the *Journal of the Chemical Society of London* (Ser. II, vol. iii, page 156), and subsequently made still more widely known through his admirable "Introduction to Modern Chemistry," leave little to be desired so far as regards accuracy of results or elegance of illustration. But these experiments require for the most part a delicacy of manipulation, which is incompatible with the hurry of the lecture room, and a skill in glass-blowing which can rarely be attained or commanded by our American teachers. Hence while seeking the same end as Professor Hofmann, but with less ample appliances, the author has devised for his own lecture-room methods of illustrating the same principles, which require less delicate apparatus and less careful attention, although as analytical methods they may not always be as accurate as those of this eminent German chemist. Following also the recommendation of Prof. Hofmann in the article just referred to, the author publishes his methods with the hope that they may serve to bring the illustrations of these fundamental laws of chemistry within the reach of the great body of teachers in this country.

Many of the methods described in this paper are alone rendered possible by the application of vulcanized rubber stoppers in the construction of the required apparatus. Hitherto these have not been made of good quality in this country, and those imported from Europe were very costly, and could only be obtained of a few invariable sizes. At the suggestion of the author, the "Boston Belting Co." now manufacture an excellent article, which they call "stopper cord," consisting of conical rolls of very elastic rubber, about 4 feet in length and varying in diameter from one-half an inch at one end, to an inch and a half at the other.* From these rolls, stoppers of any required size between the limits named may be cut with an ordinary knife and bored with a common brass cork-borer. It is only necessary to moisten the tools with water in order to prevent the adhesion of the rubber. Stoppers of this material are absolutely air-tight

* After a good deal of experience, rolls of the sizes named above have been found to be the most universally applicable, but they can be made to order of any desired dimension and at a cost not exceeding one dollar a pound. See fig. 5, where one of these rolls is shown in the fore-ground of the wood cut.

even against a full atmospheric pressure, provided that the surface of adhesion to the glass neck is at least half an inch in length.

Another material of prime importance in these experiments is sodium amalgam, which is most conveniently used when containing so large an amount of sodium as to form a hard solid. It is best prepared by gently heating a few ounces of metallic mercury in a shallow iron dish and then cautiously adding one-twentieth of its weight of sodium. The first half of the sodium should be added in very small portions at a time as the action at the beginning is exceedingly violent, but soon moderates, and at last the melted amalgam must be stirred with an iron spatula in order to incorporate thoroughly the materials. As soon as cold the solid amalgam readily separates from the dish, and should then at once be broken up into small fragments and preserved in a well stoppered bottle.

The four great typical compounds of modern chemistry are HCl , H_2O , H_3N and H_4C . Excepting the last, for which we have no new methods, we will now describe our methods of illustrating the composition of each of these in turn.

Hydrochloric acid.—The points to be illustrated in the case of this gas are all indicated by the equation $\boxed{\text{H}} + \boxed{\text{Cl}} = \boxed{\text{HCl}}$ or by the molecular expression

The first fact that HCl consists of hydrogen and chlorine gases we prove by the electrolysis of strong liquid hydrochloric acid, having previously shown in the course of the lecture how HCl is obtained from common salt, and that the liquid acid is merely a solution of the gas in water. The decomposing cell, which we use in this experiment, is represented in outline by fig. 1, which is drawn to a scale of $\frac{1}{2}$, so that both its construction and dimensions require no detailed description. The two small open glass cylinders are fitted by grinding with emery to the two tubulatures of the cell, and when the instrument is not in use are closed above with ground glass stoppers. When mounted for use the cell is filled with strong hydrochloric acid to within an inch of the upper mouths of the cylinders, and the glass stoppers are replaced by rubber stoppers, through which pass the gas delivery tubes and the conducting wires connecting with the electrodes, which are two strips of platinum foil four inches long by

one inch wide. The platinum conducting wires are welded* to the strips of foil and secured in the rubber stoppers as represented in detail by fig. 2. Into the lower end of a short piece of glass tube, which passes tightly through the rubber, the platinum wire connecting with the foil is secured by melting the glass around it, while the upper end is left open to receive the copper conducting wires from the battery, and the connection is made perfect by placing a few drops of mercury in the tube. This simple form of connecting-cup is easily made and very convenient.

As the conducting power of hydrochloric acid is very good, three Bunsen cells of the ordinary size have ample intensity and give a rapid evolution of gas. The hydrogen gas is conducted into a tall but narrow glass jar mounted in the usual way over a small pneumatic trough, while the chlorine is collected by displacement in a precisely similar jar mounted as represented in fig. 3. The mouth of this jar is closed by a ground glass plate, which is tubulated, as is shown in detail by fig. 4. This tubulature again is closed by a rubber stopper, through which pass first, the delivery tube, which reaches the bottom of the jar, and secondly an overflow tube which merely passes through the stopper, and which in the experiment should be connected by a flexible hose with a ventilator. When a larger amount of chlorine is desired the first jar may be connected with a second, and that with a third, etc., all mounted in the same way, and the exit tube from the last jar leading to a ventilator as before. When the jars are full the tubulated stoppers with their connections are removed and a plain glass cover substituted. This simple form of apparatus will be found very useful in all experiments on gases heavier than the air.

During the process of electrolysis the class will see that the two gases are evolved in nearly the same proportions, the colored gas rising in one jar as rapidly as the water falls in the other. The narrowness of the jar prevents to a great degree the diffusion of the chlorine, and a piece of white paper placed

* The platinum wire is very easily welded to the foil on a smoothed surface of a lump of quick lime which serves as an anvil. The two having been placed together in the required position on this support are first intensely heated at the points to be united, with a blow-pipe flame, and then a quick blow with a small hammer completes the work.

behind the jar, will make the line between the colored gas and the air visible to a considerable distance. When the jars are full, the qualities of the two gases may be made evident by appropriate experiments. As is well known, the gases will not be delivered in atomic proportions, until the liquid acid is saturated with chlorine. It is best therefore not to empty the cell after the experiments, but, having removed the rubber stoppers with their attachments, to close the mouth with the ground glass stoppers, and the apparatus will then be ready for the next occasion. It is also best to interpose a small wash bottle containing sulphuric acid, between the cell and the chlorine jar, for this will not only dry the gas but also equalize the hydrostatic pressure on the two delivery tubes. Decomposing cells like that represented in fig. 1, and all other forms of glassware described in this paper are made by the New England Glass Co., of East Cambridge, and can be ordered through any of the dealers in philosophical apparatus in Boston. A much simpler decomposing cell, although not quite so efficient an apparatus, can be made with a common U tube supported on a wooden stand and mounted with rubber stoppers, delivery tubes and platinum electrodes in every respect like the other.

The second point to be illustrated in regard to hydrochloric acid is, that it consists of equal volumes of its constituent gases; and although by our first experiment, if made in the way we have described, it is shown that the gases are evolved in nearly equal proportions, yet a second experiment is required to establish the absolute truth* of this important fact. The apparatus we use for this purpose is represented in fig. 5, and the details of the several parts are shown in fig. 6. The two gases are evolved together from a simple decomposing cell, shown more in detail in fig. 9, but in connection with another apparatus, and the connection of the battery with the two electrodes, is here made as before shown in fig. 2. The mixed gases pass through a small drying tube filled with pumice moistened with oil of vitriol, into an absorption tube whose construction is shown in detail by fig. 6. As the gaseous mixture is decidedly lighter than air, it is conducted to the top of the absorption tube through the small quill tube, and overflows through the short tube below. Both of these should pass air-tight through the rubber stopper, which closes the mouth of the large absorption tube and

* We here of course leave out of view the small difference which arises from the fact that the gases do not absolutely obey Mariotte's law and are therefore unequally condensed even by the atmospheric pressure. The volumes of the two gases would undoubtedly be exactly equal under greatly diminished pressure, but under the pressure of the air, the volume of the molecular weight of chlorine is about $\frac{1}{10\pi}$ less than the corresponding volume of the molecular weight of hydrogen, a difference by no means inappreciable in accurate experiments.

which should therefore have a bearing on the glass of at least half an inch. It will be noticed that while the overflow tube

is straight, the delivery tube is bent so that its open end is four or five inches above the mouth of the absorption tube. Rubber stoppers, or rather caps, must also be provided, by which the open ends both of the delivery and the overflow tubes may be closed at the right time. These are made by boring with a cork-borer *nearly* through an ordinary stopper and then pulling out the rubber core with a pair of pincers. The absorption tube should now be divided into two parts of equal capacity by means of rubber rings having however a length of three or four inches at the lower end for the absorbent liquid.

The absorption tube having been prepared as described and filled with the mixed gases, the experiment is made in the following way. The apparatus is first rapidly depressed in a solution of caustic soda (of the ordinary strength used in the laboratory) until the liquid rises in the tube to the level of the first ring. The open end of the delivery tube is now quickly closed with the rubber cap, and then the end of the overflow tube is closed in the same way—the second rubber cap having been previously dropped upon the bottom of the glass vessel containing the soda solution so as to be ready for the purpose. The tube, now perfectly air tight, is removed from the liquid and the solu-

tion of soda turned backward and forward through its entire length until the chlorine is wholly absorbed. The end of the overflow tube is now opened under water colored blue with litmus, which, as it rushes in, will be instantaneously bleached, indicating the presence of chlorine. The tube must now be immersed in the water until the level of the liquid is the same within and without, when it will be found that just one-half of the gas has been absorbed. We have now proved that one-half of the volume of gas evolved during the electrolysis of hydrochloric acid consists of chlorine, and it only remains to show that the remaining half still left in the tube is hydrogen. For this purpose the delivery tube may be connected with a water faucet and the gas burnt as it is forced out through the overflow tube.

We have now proved first, that hydrochloric acid is composed of hydrogen and chlorine; secondly, that these gases are present in equal proportions by volume, and in order to complete our demonstration of the constitution of this typical compound, we have only to prove that when these equal volumes unite to form HCl there is no condensation. This we may do either synthetically or analytically.

The synthetical experiment is made by filling the absorption tube as before with the mixed gases obtained by the electrolysis of hydrochloric acid, taking great care, as also in the previous experiment, that the tube should be perfectly dry. It will of course be necessary to have two of these tubes if both experiments are to be made in the same lecture. The tube thus filled is to be exposed for some time to bright diffused sun-light, and afterwards directly to the sun-beam until perfect combination results. If the glass is quite thick, and the rubber stopper is forced in very tight, the gases may even be exploded in the tube without danger, although this form of the experiment is always attended with some risk. When the gases are in either way thoroughly combined, the end of the exit tube is first opened under mercury, in order to prove that no condensation has taken place, and afterwards under water colored blue by litmus, when a very rapid absorption takes place, and the reddening of the water will indicate that HCl has in fact been formed.

The analytical experiment is made by decomposing HCl gas by means of sodium amalgam. For this purpose the carefully dried gas is first collected over mercury in a perfectly dry tube. This tube we assume is graduated, or at least divided into two parts of equal capacity. The tube full of gas is now slipped over the mouth of a rubber cap, which has been previously filled with the amalgam, see fig. 5 (left side of the wood cut), and sunk in the mercury trough until the liquid is just level with

the brim. This cap, which is easily made from the "stopper cord," should be capable of holding ten or twenty cubic centimeters of the amalgam, and should tightly clasp the tube. Moreover for this purpose the solid amalgam, above described, should be reduced with mercury to the consistency of a thin paste. The amalgam is now to be shaken up in the tube for several minutes until the decomposition is complete, and then the mouth of the tube may be opened under mercury. The liquid will rise to supply the place of the chlorine which has been absorbed, and on sinking the tube in the mercury trough until the level is the same within as without, it will appear that exactly one-half of the volume has disappeared. As this, however, would require a deep cistern of mercury, and as the interior surface of the tube is left in such a very dirty condition as to obscure the result, we prefer to transfer the tube to a jar of water, which, when the cap is removed, at once displaces the mercury and washes out the interior, without sensibly impairing the accuracy of the experiment.

Water.—The points to be illustrated in the case of water or rather of free steam are all indicated by the equation

There is no more striking experiment in this connection than the decomposition of water by sodium, but as made in the usual way the experiment is attended with no little danger. Sodium in certain states explodes violently when brought in contact with water, and after several accidents of this sort we have substituted the solid sodium amalgam above described with the best results. We place an ounce or more of this amalgam in a common gas flask and pour upon it water. The action is very moderate and must be assisted by a gentle heat, but on heating the flask with a gas lamp the gas is evolved rapidly and with great regularity. We collect it over the pneumatic trough and illustrate its properties in the usual way.

We illustrate the fact that water is composed of two volumes of hydrogen to every one of oxygen by the electrolysis of dilute sulphuric acid, using for the purpose the decomposing cell, fig. 1, already described. We collect the gases in two tall bell glasses standing side by side on the shelf of the same pneumatic trough. These bells are of course calibrated and the equal divisions marked by rubber rings. Six cells of Bunsen's battery, medium size, give a rapid evolution of gas.

Lastly we illustrate the fact, that when the elementary gases unite to form aqueous vapor, three volumes are condensed to two, by means of the eudiometer represented in fig. 7. This apparatus is easily made with a common iron casting well known

to steam fitters as a "return bend." Any machinist will easily adapt this casting to the required use by attaching to it, as shown in the figure, a circular iron plate to serve as a stand, by also

screwing on to one side an ordinary "elbow joint," and at the same time by carefully rimming out the three apertures so as to present smooth surfaces for the adhesion of the rubber stoppers. Into one of the openings of the "return bend" we fasten with a perforated rubber stopper, a common straight *eudiometer tube*, such for example as is ordinarily used in Bunsen's method of gas analysis, while into the second opening we fasten in a similar way an open glass tube. In the opening of the elbow joint we secure with a perforated rubber stopper as before, that convenient substitute for a stop cock so well known to chemists as a nipper tap. Last of all we obtain from the glass house a tubulated tube like that shown in fig. 8, of such size that it will cover the eudiometer tube and fit the upper end of the same rubber stopper by which the last is secured in its place. The upper end of this *outer tube* is also closed with a perforated stopper, as shown in the figure, and fine platinum wires, connecting with

the wires of the eudiometer, pass between the stopper and the glass. The lower end of the outer tube should not fit too tightly around the rubber stopper so that it can easily be removed when not wanted, moreover all the stoppers should be made of such length that while perfectly tight, they can easily be removed for cleaning the tubes.* These rubber joints, if well made, give great flexibility to the apparatus and enable it to withstand quite rough usage.

The eudiometer being thus mounted, mercury is first poured into the open limb, which is then closed with a rubber stopper and the mercury transferred by inclining the apparatus to the closed limb, this process being repeated until the eudiometer

* It is also best to place around the upper end of the eudiometer tube a rubber ring, quite narrow, but sufficiently thick to fill the annular space when the outer tube is in its place, and also perforated with a number of small holes, so that the steam or vapor, employed in the experiments, may pass freely. This ring confines the eudiometer tube and gives greater solidity to the apparatus.

tube is full. The excess of mercury is now drawn out of the open tube by the tap and this tube having been removed the instrument is left as represented in fig. 9. The eudiometer is now ready for receiving the mixed gases, which are passed up into it from a simple decomposing cell, as shown in the figure, the excess of mercury overflowing into any convenient vessel. The *open tube* is now replaced and the outer tube secured in position. It is next necessary to raise the temperature of the eudiometer tube to a point considerably above the boiling point of water and maintain it at this temperature during the rest of the experiment. This is most conveniently done by passing through the *outer tube* the vapor of amylic alcohol (fousel oil,) which may be generated in a flask placed at one side and connected by a glass tube with the upper end of the apparatus. The tubulature at the lower end of the tube should at the same time be dipped into the mouth of a glass bottle into which the alcohol may flow as fast as the vapor is condensed, and since the latent heat of this vapor is very small, this simple method of condensation will be found amply sufficient.

As soon as the temperature of the eudiometer tube is constant, which can easily be told, because the mercury column will then remain at a constant height, mercury must be poured into the open tube or withdrawn from it by the nipper tap until the level is the same in both limbs of the apparatus. It remains now only to note the volume of the confined gas and to explode it by passing an electric spark through the platinum wire already noticed, first, however, tightly closing the end of the open tube with its rubber stopper. When the stopper is removed and the mercury columns again brought to the same level it will be found that the volume of the confined gas has been reduced one-third. The result, however, is always a little too small, because aqueous vapor, even at the boiling point of amylic alcohol, 132°C ., does not exactly obey Mariotte's law, and is somewhat more condensed than the *mixed gases* by the atmospheric pressure. It would be better to employ the vapor of a liquid having a still

higher boiling point, but the results with amylic alcohol are sufficiently accurate for a lecture experiment.*

Ammonia.—The points to be illustrated in the case of ammonia are indicated by the equation $\boxed{\text{H}} \boxed{\text{H}} \boxed{\text{H}} + \boxed{\text{N}} = \boxed{\text{H}_3 \text{N}}$.

We demonstrate the composition of ammonia by the old methods which are familiar to every teacher, synthetically by passing a mixture of nitric oxyd and hydrogen over heated platinum sponge as in the beautiful experiment of the late Dr. Hare, and analytically by decomposing aqua ammonia either by electrolysis or by means of chlorine. For the electrolysis of ammonia the decomposing cell fig. 1 may be used, filling it with the strongest aqua ammonia and adding a not too small amount of sulphate ammonia in order to increase the conducting power of the liquid. The reaction is less simple than in the electrolysis either of water or of hydrochloric acid, but as the final results the gasses are evolved, very nearly at least, in atomic proportions, three volumes of hydrogen to one of nitrogen. They can be collected separately in graduated bells as in the electrolysis of water. In decomposing ammonia by chlorine we use with very satisfactory results the apparatus shown in fig. 6 and already described. For this use however a tube should be selected so thin that water may be boiled in it without risk of breaking the glass. The tube having been filled by displacement with pure and dry chlorine gas, we press down the lower end into very weak aqua ammonia (eight measures of water to one of the concentrated solution,) until the liquid flowing in through the overflow tube rises to the height of the first rubber ring. We now quickly close the delivery tube with its rubber cap and allow the absorption to continue until the tube is about half full of the ammonia water when we also close the overflow tube and shake up the liquid in the large tube until all cloudiness has disappeared from the interior. The decomposition is now complete but a considerable amount of the liberated nitrogen still remains dissolved in the liquid. To expel this we heat the tube carefully over a gas lamp until the liquid within begins to boil. On now transferring the apparatus to the pneumatic trough and opening the overflow tube under water it will be found, when the tube cools, that just one-third of the original volume is left and it can easily be shown that the residual gas

* Indeed we can obtain with free steam a result, which is sufficiently near the theory for all purposes of illustration, only it is then important that both the mixed gases and the resulting vapor should be measured under a pressure considerably less than that of the atmosphere. For this purpose a long eudiometer tube should be used and before each measurement the level of the mercury should be adjusted so that it shall stand in the open tube from 10 to 15 inches lower than in the eudiometer. Of course the difference of level must be the same at both measurements.

is nitrogen. Hence, it follows, since chlorine always combines with its own volume of hydrogen, that ammonia contains only one volume of nitrogen to every three volumes of hydrogen, the point to be proved. To complete this series of illustrations it only remains to show that in ammonia gas the four volumes are condensed to two. For this purpose some dry ammonia gas is passed up into the eudiometer tube as in fig. 9. The side tube is then replaced as in fig. 7, the mercury level adjusted and the position marked with a rubber ring. A stream of electric sparks from a Rühmkorff coil is now passed through the gas, so arranging the connections that the sparks may traverse the whole length of the gas column, and the amount of gas should be small enough to render this possible. The decomposition proceeds somewhat slowly, but after sufficient time on readjusting the level it will be found that the volume of the gas has doubled. Besides the experiments described above, there are many others, to which these same forms of apparatus are applicable; but these will suggest themselves to every teacher and it is not therefore necessary to enter into further details.

Eudiometer.—The eudiometer described above, although originally contrived for the lecture table has proved to be of still greater value in the laboratory, in all processes of gas analysis for which such an instrument is required. It is not only very cheap, simple, and easily repaired, but also equally as accurate as the most complicated apparatus. It can be used in a room of the most variable temperature; for by passing a current of water, or of steam, as the case may require, through the outer tube the temperature of the eudiometer tube may be easily maintained absolutely constant. The various gases are passed in as shown in fig. 9 and through the same opening the reagents used in the processes of analysis are readily introduced. By replacing the open tube as in fig. 7, and bringing the two mercury columns to the same level, the residual volumes may always be read off under the atmospheric pressure and at a constant temperature, indicated by a thermometer placed in the annular space between the tubes. Or on the other hand by varying the height of the mercury column in the outer tube we may reduce the gas to the same volume and measure the difference of tension according to the method of Regnault. This form of eudiometer is especially adapted for the admirable methods of gas analysis devised by Bunsen. The absorbent balls used by him are most readily introduced when the apparatus is arranged as shown in fig. 9 and the volume of aqueous vapor formed after combustion may easily be measured by replacing the current of cold water through the *outer tube* by a current of free steam. In this case it will be best to measure the gas under as great a difference of pressure as possible, in order to ensure that all the

water is vaporized and also in order to avoid the somewhat uncertain correction arising from the difference of temperature of the two limbs of the apparatus. This correction, which in most cases is insignificant, becomes important when steam is used, and it is then best to measure directly the difference of level between the mercury in the open mouth of the iron cistern, fig. 9, and that in the tube. This we do by the millimeter divisions on the eudiometer tube with the aid of a very simple contrivance. A split ring of blackened sheet brass, carrying a bent steel wire, is slipped down over the outer tube until the end of the wire just touches the surface of the mercury. The vertical height of this simple measure being known we have only to add to it the height of the mercury column above the upper edge of the ring in order to know the exact difference of level. Of course care must be taken when the measurement is made that the mercury column is vertical, but it is unnecessary to dwell on such obvious precautions, which are essentially the same with this apparatus as those so fully detailed by Bunsen in his work on "Gasometry." It is obvious moreover that the number of these corrections is considerably diminished in using this apparatus as compared with the ordinary mercury pneumatic trough, and besides the convenience and comfort of working in a warm room, it has the additional recommendation that it requires a very small amount of mercury.

The above apparatus as represented in fig. 9 may also be used with great advantage in Gay Lussac's process of determining the density of vapors. The method of using it is obvious to any one who is familiar with the process. After a weighed amount of the liquid under examination enclosed in a thin glass bulb has been passed up into the eudiometer tube it is readily converted into vapor by passing steam or the vapor of some liquid of a still higher boiling point* through the outer tube. All the measurements required in the determination are now easily made. The temperature is measured by a thermometer placed in the annular space between the two tubes and the difference of level of the mercury in the two limbs of the instrument may be most accurately determined by means of a cathetometer aided by the simple contrivance just described.

* Hydrocarbons of high but still constant boiling points, obtained by the methods of Mr. C. M. Warren, might be used with proper precautions in such determinations.

ART. XIX.—*Crystallographic Examination of some American Chlorites*; by JOSIAH P. COOKE, JR.

THROUGH the kindness of my friend Prof. Brush of New Haven, I have had the opportunity of examining some unique specimens of the Chlorites from the well known locality at Texas, Lancaster county, Pennsylvania. My observations confirm in almost every particular, those previously made by M. Des Cloizeaux and published in his admirable *Manuel de Mineralogie*, tome i, pp. 433–

451; but the perfection of the crystals at my disposal have enabled me to obtain a greater degree of accuracy in my measurements and also to develop some additional facts, especially by comparing the clinocllore from Texas, Pennsylvania, with that from Chester county in the same state and also with that from Chester in Massachusetts.

Kämmererite or Violet Chrome Chlorite.—The purest crystals of this beautiful mineral have the form represented in fig. 1. They are generally, however, macle and then appear as in fig. 2. Besides the basal plane O and the planes of fundamental rhombohedron R, these crystals also present the planes of several subordinate rhombohedrons of somewhat variable character, and in addition the basal edges of the rhombohedrons are more or less modified by the planes of hexagonal pyramids, but unfortunately the last are so strongly striated and uneven as to be wholly indeterminable. The violet Kämmererite is frequently mixed with green clinocllore, which gives to the crystals a greenish tinge. On these compound crystals the pyramidal planes are much more dominant than on the crystals of pure Kämmererite, and in this way the crystals of one mineral pass into those of the other, the violet rhombohedrons of Kämmererite merging into the green hexagonal pyramids of clinocllore. We give below in column A, the results of measurements of by far the most perfect crystal of Kämmererite we have examined. The angles italicised are certainly accurate to a minute. In columns B₁ and B₂ we give angles measured on two separate zones of a second crystal and these are important as proving the hexagonal character of the crystal. In column C, we give the fundamental angle measured on still a third crystal. The last two crystals were not so perfect as the first, but still the angles italicised must have been measured accurately within two or three minutes; so that

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