have still hesitated to mention this, as I have been hoping for an increase of optical power which would have enabled me to be quite certain on the point. My aperture (6 inches Cooke) is not adequate to put the result beyond all doubt.

As, however, the question has been raised, it is better at once to state the attempt and its result, and to ask others with greater optical power to search for the lines; taking the precaution to use the cylindrical lens close to the eye, and not to apply it to the instrument until the rays to be examined are absolutely in focus on the slit, if a slit is used. It is possible scintillation may help matters.

V. "On the relative 'Facility of Production' of Chemical Combinations." By Sir B. C. Brodie, Bart., D.C.L., F.R.S. Received November 21, 1877.

(Plate 4.)

A circumstance which cannot fail to impress the student of chemistry is the extreme paucity of chemical substances. The combinations of which he can conceive are innumerable, but those which he can realize are few—a mere sprinkling from the sea-shore sand—and, making the fullest allowance for human incapacity, it yet appears that there are natural facilities and natural obstacles in the way of making certain compounds which are independent of our skill and power.

It is my object to show that among these is to be reckoned that relative "facility of production" of chemical substances which depends on the mathematical laws of combination which are inherent in the very nature of chemical combination and unalterable. By this I mean the relative facility with which the units of matter may be constructed and taken to pieces, owing to the relation of these units to the number and kinds of the simple weights of which they are made up; and I propose to consider in what way, if any, this unequal "facility of production" is connected with these mathematical laws. Is it true that, as a matter of theory, there arises from these laws any greater facility for the production of one compound than of another, or do all stand on the same level? and, further, does experience tally with the conclusions of theory?

In my second Memoir,* on the Calculus of Chemical Operations, I have shown that the unit of every chemical substance is to be regarded as constituted by the performance of the several operations $\alpha, \chi, \xi \ldots\ldots$ upon the unit of space, and have also shown† that the ultimate analysis of every chemical event leads to the con-

* "Phil. Trans.," vol. clxvii, part i, p. 35, 1877.

† *Loc. cit.*, p. 115.

clusion that chemical events occur by the transference to and fro among the units of matter and space of certain portions of matter $w(a) . w(\chi) , w(\xi)$ . . . . , there termed simple weights, which are the results of the performance of the operations a , χ , ξ . . . ; the same unit therefore may be constructed in various ways corresponding to the differences in order in which these simple weights are transferred so as to build up the same unit of matter. Some explanation is necessary on this point.

There is nothing in the laws of combination (and these alone we are now considering) from which we can infer the performance of any one of these operations taken singly to be essentially easier or more difficult than the performance of any other; that is to say, the facility of constructing the unit a is the same as that of constructing the unit ξ; but when we consider combinations of more than one operation the case is different. The combinations of the operations a and ξ taken two and two together are a^2, $a\xi$, and ξ^2; the combination a^2 is unknown, $a\xi$ is the unit of water, and ξ^2 the unit of oxygen. Now, there is only one way in which the unit ξ^2 can be produced, namely by the successive performance of two operations ξ. Similiarly, there is only one way in which a^2 may be produced. But there are two ways in which the unit $a\xi$ may be produced, namely by first performing the operation ξ on the unit of space and then the operation a, in which case the unit $a\xi$ is the result; and also by first performing the operation a and then the operation ξ, which results in the combination ξa. These two results (so far as our present purpose is concerned) are identical, as follows from the commutative law $a\xi = \xi a$ demonstrated in Part I.* We hence say that the "facility of production" of the unit $a\xi$ is twice that of the respective units a^2 and ξ^2. The ternary combinations of a and ξ are a^3, $a^2\xi$, $a\xi^2$, and ξ^3; a^3 and $a^2\xi$ are unknown, $a\xi^2$ is the unit of binoxide of hydrogen, and ξ^3 is the unit of ozone. On these principles the respective "facility of production" of these units is—

$$\begin{array}{r} a^3 \ldots 1 \\ a^2\xi \ \ldots 3 \\ a\xi^2 \ldots 3 \\ \xi^3 \ldots 1. \end{array}$$

Again, the ternary combinations of the operations a and ν are a^3, unknown; $a^2\nu$, the unit of ammonia; $a\nu^2$, the unit of nitrogen; ν^3, unknown. The respective "facilities of production" of these units are—

$$\begin{array}{r} a^3 \ldots 1 \\ a^2\nu \ \ldots 3 \\ a\,\nu^2 \ldots 3 \\ \nu^3 \ldots 1. \end{array}$$

* "Phil. Trans..," part ii, 1876, p. 796.

Similarly, the "facility of production" of the unit of the hydrocarbon valerylene $\alpha^4\kappa^5$ is to the "facility of production" of the hydrocarbon benzene $\alpha^3\kappa^6$ as 126 to 84. The measure of the "facility of production" of a unit of matter being in all cases that number which expresses the different ways in which the operations may be permuted by which that unit is made. It is important to observe that the comparison which is here effected is that between the "facility of production" of the units of homogeneous substances, namely units severally composed of the same number of simple weights. Thus we can compare the "facility of production" of valerylene $\alpha^4\kappa^5$ and benzene $\alpha^3\kappa^6$, but we have no means of effecting this comparison between the unit of valerylene $\alpha^4\kappa^5$ and the unit of propylene $\alpha^3\kappa^3$.

That this "facility of production" is among the causes which determine the existence of certain units of matter to the exclusion of others can hardly be denied, as a speculative truth, by anyone who admits that these units are built up from simple weights in the manner I have described, but the action of this cause might be so veiled from our view, by the action of other causes, that we might never be able to detect it by the isolation of its effects. The verification of a scientific theory is effected by comparing the results indicated by that theory with the actual results of experience, and no physical theory can be regarded as demonstrated unless it can stand the test of this comparison. The system of combinations which in the present instance lends itself most readily to this verification is the system of hydrocarbons. This system contains some eighty-eight combinations, and, although limited as regards the full attainment of the object in view, is yet far more extensive than any other similar binary system. The composition, too, of the several units of the system is well determined. The gaseous density of the hydrocarbon being, in numerous cases, ascertained by experiment, and, where this is not the case, being determined by reasoning, generally of a very conclusive character.*

Before proceeding further, I will give a list of the hydrocarbons to be considered, and their symbols. For facility of reference, they are arranged according to the powers of α.

1	unit of	space.	$\alpha^2\kappa^3$	unit of	allylene.
κ	,,	carbon.	$\alpha^2\kappa^6$	,,	phenylene.
α	,,	hydrogen.	$\alpha^3\kappa^2$	,,	ethane.
$\alpha\kappa^2$	,,	acetylene.	$\alpha^3\kappa^3$	,,	propylene.
$\alpha^2\kappa$	,,	methane.	$\alpha^3\kappa^4$	,,	crotonylene.
$\alpha^2\kappa^2$	,,	ethylene.	$\alpha^3\kappa^5$	,,	valylene.

* In compiling this list, pains have been taken not to introduce non-existing hydrocarbons. It has not appeared necessary, in all cases, to verify the list by reference to the original authorities, but it may be taken as representing the existing view of the subject as given in the best text-books. In making these references, I have been much indebted to my friend Mr. W. F. Donkin, who has gone into the question with the greatest care.

$\alpha^3\chi^6$ unit of benzene.
$\alpha^3\chi^8$,, phenylacetylene.
$\alpha^4\chi^3$,, propane.
$\alpha^4\chi^4$,, butylene.
$\alpha^4\chi^5$,, valerylene.
$\alpha^4\chi^7$,, toluene.
$\alpha^4\chi^8$,, cinnamene.
$\alpha^4\chi^{10}$,, naphthalene.
$\alpha^4\chi^{12}$,, ethine naphthalene.
$\alpha^5\chi^4$,, tetrane.
$\alpha^5\chi^5$,, amylene.
$\alpha^5\chi^6$,, diallyl.
$\alpha^5\chi^7$,,
$\alpha^5\chi^8$,, xylene.
$\alpha^5\chi^9$,, allylbenzene.
$\alpha^5\chi^{10}$,, dihydronaphthalene.
$\alpha^5\chi^{11}$,, methylnaphthalene.
$\alpha^5\chi^{12}$,, diphenyl.
$\alpha^5\chi^{13}$,, fluorene.
$\alpha^5\chi^{14}$,, anthracene.
$\alpha^5\chi^{16}$,, pyrene.
$\alpha^6\chi^5$,, pentane.
$\alpha^6\chi^6$,, hexylene.
$\alpha^6\kappa^7$,, œnanthylidene.
$\alpha^6\chi^9$,, cumene.
$\alpha^6\kappa^{10}$,, phenylbutene.
$\alpha^6\chi^{12}$,, ethylnaphthalene.
$\alpha^6\chi^{13}$,, diphenylmethane.
$\alpha^6\chi^{14}$,, stilbene.
$\alpha^6\chi^{15}$,, methylanthracene.
$\alpha^6\chi^{16}$,,
$\alpha^6\chi^{18}$,, chrysene.
$\alpha^7\chi^6$,, hexane.
$\alpha^7\chi^7$,, heptylene.
$\alpha^7\chi^8$,, caprylidene.
$\alpha^7\chi^{10}$,, cymene.
$\alpha^7\chi^{14}$,, benzyltoluene.
$\alpha^7\chi^{16}$,, dimethylanthracene.
$\alpha^7\chi^{17}$,, naphthylphenylmethane.
$\alpha^7\chi^{18}$ unit of diphenylbenzene.
$\alpha^7\chi^{20}$,, dinaphthyl.
$\alpha^7\chi^{22}$,, idrialin.
$\alpha^8\chi^7$,, heptane.
$\alpha^8\chi^8$,, octylene.
$\alpha^8\chi^9$,,
$\alpha^8\chi^{10}$,, terpene.
$\alpha^8\chi^{11}$,, amylbenzene.
$\alpha^8\chi^{14}$,, anthrcaene hexhydride.
$\alpha^8\chi^{15}$,, benzylxylene.
$\alpha^8\chi^{19}$,, triphenylmethane.
$\alpha^9\chi^8$,, octane.
$\chi^9\chi^9$,, nonylene.
$\alpha^9\chi^{10}$,, rutylene.
$\alpha^9\chi^{12}$,, amyltoluene.
$\alpha^9\chi^{16}$,, benzylcumene.
$\alpha^9\chi^{18}$,, tetramethylanthracene.
$\alpha^9\chi^{20}$,, tolyl diphenylmethane.
$\alpha^9\kappa^{24}$,, triphenylbenzene.
$\alpha^{10}\chi^9$,, nonane.
$\alpha^{10}\chi^{10}$,, diamylene.
$\alpha^{10}\chi^{13}$,, amylxylene.
$\alpha^{10}\chi^{26}$,, tetraphenylethylene.
$\alpha^{11}\chi^{10}$,, decane.
$\alpha^{11}\chi^{26}$,, tetraphenylethane.
$\alpha^{12}\chi^{11}$,, endecane.
$\alpha^{12}\chi^{19}$,, dimesityl methane.
$\alpha^{13}\chi^{12}$,, dodecane.
$\alpha^{14}\chi^{13}$,, tridecane.
$\alpha^{14}\chi^{15}$,, benylene.
$\alpha^{15}\chi^{14}$,, tetradecane.
$\alpha^{15}\chi^{15}$,, triamylene.
$\alpha^{15}\chi^{16}$,, cetenylene.
$\alpha^{16}\chi^{15}$,, pentadecane.
$\alpha^{16}\chi^{16}$,, cetene.
$\alpha^{17}\chi^{16}$,, hexdecane.
$\alpha^{20}\chi^{20}$,, tetramylene.
$\alpha^{27}\chi^{27}$,, cerotene.
$\alpha^{30}\chi^{30}$,, melene.

With the view of effecting a comparison between the hydrocarbons actually produced and their relative "facility of production," as indicated by theory, I have constructed the following map. The nature of this map will be readily understood from inspection. So far as the numbers are concerned, it is the arithmetical triangle of Pascal. Each square contains a number, and the symbol of a hydrocarbon. "A line drawn so as to cut off an equal number of units from the top horizontal row and the extreme left-hand vertical column, is called a base. The bases are numbered, beginning from the top left-hand corner. Thus, the tenth base is a line drawn through the numbers 1, 9, 36,

84, 126, 126, 84 36, 9, 1."* These numbers, it will be observed, are the numerical coefficients of the several terms in the expansion of $(a + \kappa)^9$ and the symbols in the corresponding squares the symbols corresponding to those coefficients. Thus, for example, in the case of the fourth base, which passes through the numbers 1, 3, 3, 1, we have $(a + \kappa)^3 = a^3 + 3a^2\kappa + 3a\kappa^2 + \kappa^3$. The numerical coefficients, as is well known, express the number of ways in which the letters in the corresponding symbols may be permuted. Now, the "facility of production" of the hydrocarbon varies with the number of these permutations, so that in each square the symbol is associated with the number expressing its "facility of production." If experience be concordant with theory, the actually existing hydrocarbons which appear on the several base-lines (between which it is our object to effect the comparison in question) will be found in those squares in which the highest numbers appear. Now, if a perpendicular be let fall upon any base from the upper left-hand corner of the square in the top horizontal row, this line will either pass through the square containing the greatest number or will pass between two such squares, the numbers equally diminishing on each side. The perpendicular drawn through all the bases will be termed the axis or main diagonal of the system.

The squares in which the actually existing hydrocarbons appear are in the map shaded; there are no known hydrocarbons corresponding to the plain squares. If we follow the course of the axial line, it will be perceived that, up to the twentieth base, the squares through which the axis passes and the squares which lie immediately to the right and to the left of the axis, with one exception, are coloured grey, so that, up to this point, all the hydrocarbons which have theoretically the greatest "facility of production" have actually been produced. Further, a close inspection will show that there is a decided tendency in the system to approximate to this central line.

It does not follow, from these considerations, that "facility of production" should be the only cause determining the actual existence of the hydrocarbons. The case is not so simple as that of drawing white and red balls from an urn or cards from a pack. At one time the efforts of chemists may be mainly, although even unconsciously, directed to filling up one part of this system; at another time to filling up another part; efforts which may have their origin in testing the truth of speculations or possibly in the discovery of some one method or one hydrocarbon;† but the remarkable fact remains that, notwithstanding the operation of these multifarious causes acting in various

* *Vide* Todhunter, "History of the Theory of Probability."

† Thus the great attention which has of late been paid to the derivatives of phenyl has caused what may be considered as an exaggerated growth of the system to the right of the main diagonal.

directions, the paramount influence of this "facility of production" should still be apparent as the one cause which determines the general aspect of the system.

The causes I have mentioned would obviously determine an unequal growth of the system and preclude a perfectly symmetrical arrangement, at any given time of observation, of the cluster of hydrocarbons around the axial line. How far this inequality is due to accidental causes, and how far to the operation of permanent causes acting in one direction, is impossible, from the slender data we possess, to say, but the chemist should ever be alive to the detection of permanent deviations, in the form of the actual system, from the form indicated by theory, for in such observations lie our best means of detecting the existence of other causes affecting its growth, besides that predominant cause which has been here discussed.

January 31, 1878.

Sir JOSEPH HOOKER, K.C.S.I., President in the Chair.

The Presents received were laid on the table and thanks ordered for them.

The following papers were read:—

I. "Further Researches on the Minute Structure of the Thyroid Gland." Preliminary Communication. By E. CRESSWELL BABER, M.B. Lond. Communicated by Dr. KLEIN, F.R.S. Received November 21, 1877.

In a previous communication to the Society* I have described some observations made on the minute anatomy of the thyroid gland of the dog. Since then I have extended these observations, under the direction of Dr. Klein, to the glands of other vertebrate animals. The chief results as yet arrived at will be very shortly described in the present communication, a full account of them being reserved to a future paper.

Lymphatics.—In the thyroid gland of the dog I have described a dense rounded network of lymphatics traversing the gland in all directions, and consisting of lymphatic vessels, tubes, and spaces. A similar system of lymphatics has been observed in the glands of other mammalia, as kitten, rabbit, man, and horse; the extent of distribution, however, as shown by the injection, appears to vary in different

* "Philosophical Transactions," 1876, vol. clxvi, pt. ii, p. 557.