Michel-Eugene Chevreul, 1786-1889.¹

By Prof. HENRY E. ARMSTRONG, F.R.S.

RECENTLY, in London, we celebrated the centenary of the discovery of benzene by Faraday and in so doing took occasion to proclaim Faraday's greatness as a chemist. The commemoration was remarkable, because it was held by the Royal Institution, where the discovery was made, in conjunction with three other associations: the Chemical Society, the Society of Chemical Industry and the Association of British Chemical Manufacturers. This was the first time these three bodies, which collectively represent all the interests of British chemistry, have shown themselves to be actuated by one purpose and have elected to work to a specific end, in harmonious, declared co-operation. In England, we regard the event as a happy presage of the union we have long sought to achieve—the union of our chemists into a single professional organisation.

Now, a further step is taken along the same path. I am charged by the Royal Society of London and the three bodies I have mentioned, which again act as one, with the honourable and most gratifying task of conveying to our French colleagues, their united warmest congratulations upon this occasion. We not only desire to join in paying homage to Chevreul's memory: we also desire both to carry on the work we began, with the powerful aid of French men of science, in London and to aid them in reminding their public of the inestimable value of genius and in enforcing upon the attention of the rising generation of students the value of the examples before them in the work of the famous men of the past.

The world of to-day is accustomed to take advantage of the work its leaders do for it, without in the least attempting to understand what leadership is and entails. Our need of leadership, the paucity of leaders, was never more obvious, perhaps never so great. We are too prone to think in terms of majorities—forgetting that evil may often, more easily than good, command a majority. We do not sufficiently realise how much the War has cost the nations in leadership. On such occasions as this, we do well to pose such problems before the public.

We have a remarkable series of English essays, too little read to-day, I fear, on "Hero-Worship," delivered by our great man of letters, Thomas Carlyle, the historian of the French Revolution. His heroes were: Odin and Mahomet; Dante and Shakespeare; Luther and Knox; Johnson, Rousseau and Burns; Cromwell and Napoleon: representing divinity, poet, priest, letters and king. Science was not considered: letters have yet to fathom its mystery, if indeed it be fathomable by the literary mind. Even Anatole France, though respectful, is fearful of us; he even goes so far as to say: "Our chemists and our professors of science are almost to a man anarchists." He probably failed to recognise, that the religion of the future, if indeed there be one, will be fashioned out of pure knowledge. Being, we are told, "liberated from religious belief, lacking the organ of superstition," he

was perhaps unable to realise that the true office of science is to create belief by destroying dogma: to govern by necessary commandments.

Meetings on such occasions as this serve to correct unjustified literary partiality and misreading of our character. We can rejoice in what Chevreul did for civilisation, not against it: he was a veritable torch-bearer: he not only made the torch a thing of beauty to the eye but also deprived it of all offence to the nose. In doing so, he liberated glycerol but it remained for Sobrero to convert this into an engine of war.

Were Carlyle writing to-day, he would perforce include science in his gallery of heroes. The choice of representatives would be difficult. Certainly, one of the first to consider would be Lavoisier, the greatest philosophic chemist of all time. Then would come Faraday, I think, especially on the grounds of his moral outlook. To France would fall another nomination, that of Pasteur, as a great humanitarian. Anatole France would never have classed us as ultimately dangerous had he studied such examples. It would have interested him to know that, in 1824, the celebrated home of Sir Walter Scott, at Abbotsford, was lit by oil-gas, made from material which his countryman Chevreul was the first to study, the "gas" from which Faraday, a year later, was to isolate benzene. Not to be outdone by the Church, at the recent celebration, in London, of Faraday's discovery, in the evening, at the banquet in the Hall of the Goldsmiths' Company, one of the private palaces of our City of London, no less a number was lit than 578 of the candles made possible by Chevreul's invention of 1825. In such manner was honour done to the coming of benzene, in such manner was the chemist's "open chain" connected with the "closed." The great hall in which we met is one of the few now illuminated in accordance with ancient custom—by burning oil-gas, *in situ*, as it is produced from Chevreul's candle with the aid of the "retort" patented by Cambacères in 1834. To-day, Chevreul and Faraday march arm in arm, illuminating the world—the one bearing the candle, the other the electric torch. Anatole France, doubtless, in his time, burnt many candles as midnight oil—how then could he call us anarchists, unless it were because of the support our work gave to his anticlericalism? Had it not been for the constitutional inability of the literary to understand the experimental mind, he must surely have treated us as the most lovable of brethren.

Working as chemists, Chevreul and Faraday between them, practically at the same time, laid the foundations of organic chemistry: Chevreul of its open or paraffinoid, Faraday of its closed or phenoid systems. In our inability to escape from ancient practice, motorists to-day, fire-worshippers as they are, finding it to their advantage to associate the two types of combustible, unconsciously, the world over, render their burnt offering to the memory of the scientific fathers that begat them.

Chevreul's has long been an honoured name in England. He was elected a foreign member of the Royal Society in 1826 and received the Copley Medal,

¹ Address delivered at the fifth Congress of Industrial Chemistry organised by the French Society of Chemical Industry, on October 11, at the centenary celebrations of Chevreul's work on fats.

its highest honour, in 1857. He was elected a foreign fellow of the Chemical Society in 1849.

In the obituary notice published by the Royal Society (1889), it was said:

He will be known for his researches on the contrast of colours but his great work was that by which he cleared up the constitution of the fixed oils and fats and established the theory of saponification. Few scientific men surviving were even born² when this important research was commenced—a research in the course of which he laid the foundation of the method now universally followed in the study of organic compounds, by showing that an ultimate analysis by itself alone is quite insufficient and that it is necessary to study the substances obtained by the action of reagents on that primarily presented for investigation.

The notice given in the *Journal of the Chemical Society* (1890) is in similar terms. His investigations are said "to cover the whole of chemistry, branching out into physiological chemistry, hygiene and physics." In our survey we are carried far back, in the history of the development of the method of chemical inquiry, in considering Chevreul's early contributions. I have difficulty too in picturing his masterful activity—it was so ceaseless and varied. He thoroughly deserved the title he was accorded of "Encyclopédie vivante." To-day, students know him only as a chemist who lived to be more than a century old and was the discoverer of the higher fatty acids. Few will have seen the wonderful bibliography prepared, at the time of his centenary, by M. Godefroy Malloizel. The items catalogued number 506, including several comprehensive treatises. In our English Royal Society's Catalogue of Scientific Papers, 233 titles appear under his name, between the dates 1806 and 1884.

Born at Angers in 1786 and educated there, at the École Centrale, in 1803, at the age of seventeen, he went to Paris and was admitted by Vauquelin, the discoverer, in 1797, of the element chromium, to his chemical manufactory but soon became chief of the laboratory. In 1810, Vauquelin appointed him his assistant in his course of applied chemistry at the Museum of Natural History. In 1813 he obtained the chair of chemistry at the Lycée Charlemagne. In 1824 he became professor of special chemistry at the Gobelins tapestry factory and succeeded Roart as director of the dye works.

Chevreul began to publish in 1806. His early work was of a miscellaneous character. He began to study indigo in 1807 and was the first to recognise that it occurred naturally in "its lowest stage of oxidation" as indigo white. In 1811, he isolated the yellow colouring matter quercitrin. Morin and luteolin were discovered by him in later years. In 1815 he proved that diabetic sugar was identical with starch (grape) sugar. He began his studies of the saponification process in 1810 and recorded the results of his examination of the fats, in a series of papers, between 1813 and 1818. He discovered butyric, valeric and caproic acids in 1818 and oleic acid in 1823. In 1832 he prepared kreatin from meat extract. He studied wool-fats in 1853. His attempt, in conjunction with Braconnot and Gay Lussac, to establish the stearin candle

industry receives notice at other hands. It is well known that the manufacture was not successful until after the introduction of Milly's improved process of saponifying with lime and the invention of the plaited wick by Cambacères in 1834. In its early stages, the industry was largely developed in England by Price and Co. It has now reached colossal dimensions, though the hydrocarbon paraffin has largely taken the place of stearic acid.

Like Faraday, Chevreul was no mere laboratory worker: he was not only a philosopher but also a systematist and logician of the first order. His scientific writings are all models of clear and simple statement and a complete justification of the motto he adopted, from Malebranche, as his guiding principle, "On doit tendre avec effort à l'infailibilité sans y prétendre."

Recognising "les inconvénients d'exposer de nombreuses recherches sur un même sujet dans une suite de mémoires," in 1823, he published, in book form, a comprehensive account of his work on the fats—"Recherches chimiques sur les corps gras d'origine animale," which he dedicated to Vauquelin.

The point of view from which his work generally had been undertaken is clearly defined in the introduction to this volume, in the following terms:

On dit que la chimie se compose de faits, mais des faits seuls ne constituent pas cette science; car lorsqu'on donne des définitions générales, lorsqu'on forme des groupes de corps d'après des propriétés analogues et des propriétés différentes, il a fallu nécessairement interpréter des faits déjà observés pour établir les rapports qui les lient. Lorsqu'on définit, il y a donc des rapports établis et on reconnaît des propriétés de différent ordres, quant à l'importance qu'on attribue à chacune d'elles: dès lors il y a plus que des faits, quoique en dernier ressort toute interprétation, toute définition, doivent s'appuyer sur des faits bien observés. Priestley a découvert un grand nombre de corps importants; il a reconnu la plupart de leurs propriétés et certainement il a fourni à la science plus de faits proprement dits que Lavoisier; cependant, sans que nous ayons l'intention de diminuer en rien la gloire du savant anglais, nous pouvons dire, sans crainte d'être démenti, que la postérité a placé Lavoisier au-dessus de lui. Quelle en est la cause, si ce n'est pas la manière dont les faits ont été interprétés? Ce qui est vrai pour les faits qui ont servi de base à la théorie antiphlogistique, doit l'être pour ceux qui restent à découvrir: nous pensons donc qu'au lieu de recueillir sur des sujets très différents des faits qui manquent de corrélation, il est préférable pour le progrès de la science de rassembler le plus possible des faits analogues, de les coordonner ensemble, afin d'en déduire les conséquences générales, qui seules peuvent imprimer à un ensemble de faits le caractère constitutif de la science.

Lorsque nous avons commencé l'étude des sciences physiques, nous avons été frappés du vague qui régnait alors dans la chimie organique, en même temps que nous avons aperçu l'étendue des applications qu'on peut faire de cette branche de la philosophie naturelle aux sciences physiologiques et anatomiques, à la médecine et à ces arts nombreux dont l'objet est de préparer avec la matière des corps organisés des substances utiles à l'homme. Tels sont les motifs qui nous ont engagés depuis longtemps à réfléchir sur tout ce qui se rattache aux connaissances chimiques des produits de l'organisation.

² Chevreul was only eight years old when Lavoisier was executed.

Nous nous sommes appliqués à connaître les principes que l'on sépare immédiatement des végétaux et des animaux, parce que *cette connaissance est la base de la chimie organique et de toutes ses applications.*

In a second volume, published in 1824, "Considérations générales sur l'analyse organique immédiate et sur ses applications," Chevreul dealt more generally with the methods to be followed in examining natural products. The copy of this book that I have consulted came from Faraday's library; that dealing with the fats was a presentation copy to Mitscherlich. He not only discusses the use of solvents but also the mode of action of the various chemical agents. The following quotation will serve to illustrate the crude state of knowledge at the time: "M. Berzelius a dit que la fibrine du sang, l'albumine, la gélatine, éprouve sur l'influence de l'alcool et de l'éther une altération telle qu'une partie de leur matière est transformée en substance grasse adipocire."

After describing his experiments to test this statement, Chevreul concludes: "J'ai été ainsi conduit à reconnaître que les substances grasses contenues dans l'alcool et dans l'éther qui ont été mis en contact avec des tendons, etc., sont simplement extraites de ces substances et non produites aux dépens de leur éléments."

What Chevreul would have attempted, what he would have achieved, had he remained a chemist and a free lance, it is difficult to say. I venture to think that systematic inquiry in organic chemistry might have been made more *de règle* at a far earlier date than it was. The fates determined that he should be called off to deal with the problems of colour and of practice. No one has handled them more comprehensively, more logically, than he did, in his capacity of Director of Les Gobelins. Not satisfied with treating the subject as a chemist, he at once proceeded to inquire into the effect of contrast in colour—not only in tapestry fabrics but also in clothing, in house decoration and even gardening—including the planting of the dahlia, the now fashionable flower. His great work "La Loi du contraste simultané des couleurs," first published in 1839, was long out of print. A new large quarto edition, with a preface by his son, was issued by l'Imprimerie Nationale in 1889. That he retained his interest in colour to the last is proved by his communication to the Institute, in 1884, in his ninety-eighth year, entitled "La Vision dans ses rapports avec les contrastes des couleurs."

Chevreul ranks alone as a student of the philosophy of the dyer's art apart from his craft. His works deserve renewed attention, at a time when colour plays so important a part in our civilisation. Judging from what I have seen at the Exposition Internationale des Arts Décoratifs, modern artists might consult them with advantage.³ The first to study indigo, the dyestuff

which still ranks before all others in importance, no one would have been better able to appreciate the extraordinary advance, within recent years, in our knowledge of colouring matters, both scientific and practical: he would have specially welcomed the discovery of the superlatively resistant indigo-like dyestuffs derived from anthracene and their appearance, in commerce, in the "lowest stage of oxidation," ready for application to the fibre by the dyer.

Some day, we may well compel the admiration of such achievement by the literary mind, even by the poet, if we can but paint the marvellous story in sufficiently simple terms and make clear what it is that has fired the heart of the chemist to match himself against Nature—even to her undoing. Chevreul was certainly one of the earliest and boldest among the conspirators and were he with us, to-day, would undoubtedly have sought to impress upon the public mind the marvellous development our art has undergone since he became its votary—within a single century.

Chevreul was greatly devoted to historical and philosophical study and deeply interested in making known the principles of scientific inquiry. In his "Histoire des connaissances chimiques," published in 1866, he speaks of his long friendship with Ampère and Frédéric Cuvier, begun forty-five years previously and refers to their frequent discussions on the classification of human knowledge. This work is full of sage reflexions. Let me quote one:

L'erreur prise pour vérité a encore le grave inconvénient de mettre obstacle au progrès de la science, parce que si une découverte véritable annoncée est contraire à cette erreur, il arrivera que les partisans de celle-ci repousseront la découverte, c'est-à-dire la vérité plus ou moins longtemps.

Telle est la raison sur laquelle je m'appuie pour réduire l'enseignement élémentaire et l'enseignement dit professionnel à ce qui est vrai et susceptible d'être facilement démontré tel. Car beaucoup de gens qui se disent partisans du progrès, ne voient pas que des erreurs promulguées par ces enseignements comme des vérités, sont autant de semences qui, en se développant dans de jeunes intelligences ou des intelligences d'adultes que nulle étude n'a préparés à les juger, deviennent des opinions erronées qui seront un jour les plus grands obstacles à la propagation de la vérité, c'est-à-dire à ce même progrès que l'on veut favoriser.

L'importance que j'attache à la destruction de l'erreur explique mon ardeur à propager la méthode.

We may well take such admonition to heart, in these days of unchecked hypothesis. If "l'enseignement

true feeling. In fact, the appreciation of colour seems now to have passed mainly into the charge of the textile workers, who not only have an endless gamut of tones at their disposal but are also able to produce varied effects of surface texture, unknown in Chevreul's day, which greatly enhance their power to please.

A happy accident gave us also an opportunity of appraising the value of pure natural colour. Lunching at Foyot's, we were opposite a lady wearing a most becoming "hat," of expensively simple design, a neutral light-brown in colour, who was sitting with her back turned to a window through which the brilliant rays of a midday sun came streaming in; these were evidently caught by a prismatic wedge, for every now and then, as she moved forwards and backwards, a complete spectrum hung upon her brow and the curved edge of the bonnet—the decorative effect was exquisite, one producible by no conscious art.

A greater opportunity was to come. In the interval, in sunshine and shower, we have explored our English Lakeland region and seen the full glory of the bow resting upon the brows of the fells and upon wondrously sculptured slopes clothed with harmonies of wetted autumnal colour—colour of indescribable, inconceivable beauty, yet mostly traceable to Faraday's benzene and to contrasts beyond compare in which Chevreul especially would have gloried.

³ In Paris, we had many opportunities of appreciating the importance of Chevreul's efforts to direct the use of colour and of noting how great is the part to-day played by its glory. The public gardens, those of the Luxembourg especially, were ablaze with it, the Dahlia being the predominant factor in its production. At the Exhibition of Decorative Arts it was everywhere to the fore. Many most exquisite effects and contrasts were to be seen in jewellery. Striking beyond measure, however, was the wondrous exhibit of the Lyons silk manufacturers. The colour contrasts and patterns were not always such as Chevreul would have advised but marvellously effective, for the most part. To judge from the display at the Salon, in comparison with that at the Exhibition, painters are no longer mindful of the rainbow, seeking to attract rather by abrogating than by following the harmonies therein disclosed. The potters, too, are behind in evoking pleasing effects and the glass makers also seem to be lacking in

dit professionnel" were reduced "à ce qui est vrai et susceptible d'être facilement démontré tel," how much higher would be the task of the teacher and how much more competent the pupil as student and worker.

That philosophical subjects continued to fill his mind is clear from his communication to the Institute, in 1883 (*C. R.* 96, 1521): "Considérations générales sur les méthodes scientifiques et applications à la méthode *a posteriori* de Newton et à la méthode *a priori* de Leibnitz," in which he discussed the diametrically opposite methods of the two philosophers. It would be to the advantage of students, if a complete edition of Chevreul's works could be published, at a cheap price. They would be of great value, if only as examples of style.

Like Faraday, Chevreul turned his attention to occult phenomena and dealt specially with certain aspects of occultism, as member of a Commission of three appointed by the Academy, in 1853, to examine a memoir by M. Riondet "sur la baguette divinatoire employée à la recherche des eaux souterraines"; also a letter, by M. Koeppein, "sur les tables tournantes." His report was published in book form under the title "De la baguette divinatoire, du pendule dit explorateur et des tables tournantes." I have had at my disposal the autograph copy of this book presented by Chevreul to the Royal Society of London. He was prepared to undertake the task, having twenty years before addressed a letter to his friend Ampère "Sur une classe particulière de mouvements musculaires," discussing experiments which he had made in 1812 to test the statement: "Qu'un pendule formé d'un corps lourd et d'un fil flexible oscille lorsqu'on le tient à la main au-dessus de certains corps, quoique le bras soit immobile." Like all who have discussed such subjects critically and exactly, he came to the conclusion that the manifestations were to be referred to no "faculté surnaturelle," but to "unconscious cerebration."

Chevreul's work on the fats was limited to the recognition of their proximate constituents. A long series of workers has since laid bare their molecular structure: of these Dumas and Boullay, Gerhardt, Würtz and Berthelot, not forgetting Schorlemmer, were among the first. The story is the story of the development of structural chemistry—a colossal work of the human intellect which is too little appreciated, even in scientific circles.

It is noteworthy that, at this early date, he discussed the possibility of preparing organic substances by artificial means and definitely decided that it is likely that they would be so produced. Four years later, Wöhler was to make urea, thus breaking down for ever the barrier between Nature and our art. To-day the Badische Co. is counting upon a production of 20,000 tons per annum and urea may well become the sole artificial nitrogenous fertiliser used by agriculturists. Indigo, Chevreul's early love, is fast being displaced by synthetic indigotin, the world production of which is already rated at 9000 tons (dry weight) per annum. The other natural dye-stuffs he studied are all but unused—the fats alone still carry the bloom of their natural origin, though, taught by Sabatier, we are now accustomed to pale the fresh complexion of those that are oils with hydrogen.

Our art has thus gone far in copying Nature but she

still defies us to read and understand her purpose. We have also done much to alleviate man's ailments and are vastly more powerful. Nevertheless we are no happier nor better attuned to her beauty and goodness. Our art is not yet true art. Would Chevreul have been satisfied with our slavish worship of mere measurement, great as was his devotion to accuracy? Would he not have deprecated our insatiate desire to manufacture everything—our attempts to waive aside Nature's activity in every possible way? Would he not have asked for a less academic and broader treatment—for a greater display of humanity, for more reverence for the great scheme we presume to dissect? No one was more alive to the frailty of the human spirit but no one more conscious of its powers when rationally used. True science is dangerously far from the public ken and we need to recognise the duty that is upon us to bring home to all the infinite possibilities it affords of a future worship of abstract truth.

Chevreul, to-day, would be astounded at the lengths to which we have been carried by application of the philosophical methods of study of which he was so stalwart an advocate throughout his life. We know the structure of the diamond, thanks to the confirmation X-rays have afforded of the chemist's conception of the carbon atom, built upon the foundations laid by Frankland and Kekulé, by Biot, Pasteur, Le Bel and van't Hoff and established by the labours of a vast army of patient students of organic structure. We can, in fact, assert, that the diamond is made up of individual units—carbon atoms—commanding tetrahedral domains. The contiguous units are arranged alternately, as tetrahedra may be, base downwards and base upwards, lines between their centres forming a zigzag and meeting at an angle of 109° , the tetrahedral angle. Recent measurements, made by Dr. Müller, at the Royal Institution, of exceptionally good crystals of stearic acid, show that the carbon atoms in this compound meet at this same angle. In fact, the saturated fatty acids are simple rods of carbon atoms, clothed with hydrogen atoms along their length, their acidity being determined by the presence of a terminal group in which Lavoisier's oxygen is substituted for hydrogen.

This is a strange structure in comparison with that of Faraday's benzene, which may also be pictured as being hewn straight out of the diamond but as consisting of compact hexagonal blocks of six carbon atoms.

Why Nature, in making the fats, should build such extraordinary scaffold-pole like molecules is passing strange. The field is full of problems: it is surprising that so little attention has been given to it (see E. Frankland Armstrong, Presidential Address, Society of Chemical Industry, Liverpool, 1924). I have here a solid model of the geometrical structure of the fatty acids which I owe to Mr. William Barlow, F.R.S. It is a veritable *bougie stéarique*, built, not wastefully, in cylindrical form but so that the individual units interlock to fill space. Mr. Barlow and I believe this model to be worthy of special attention, as it has features which serve to represent peculiarities hitherto unexplained in the chemical behaviour of the fats and paraffinoid compounds generally. If the hydrogen atoms were arranged around the carbon atoms tetrahedrally, they would serve to isolate them in space and the formation of crystalline masses from such units

would seem to be "impossible"; moreover, such compounds would be chemically neutral, assuming hydrogen to lose all affinity when it unites with carbon. In the model before you, as in that of benzene, the unit of affinity and, therefore, the hydrogen atom is a regular dodecahedron. Four such dodecahedra arranged in a pyramid represent the carbon unit: consequently, the dodecahedral units are distributed in two layers. The hydrogen atoms, in the fatty acids, are all brought down, as they are in the model of benzene, into these two layers: therefore, an upper and a lower face in the model are free carbon surfaces. The models can, in consequence, be superimposed at these faces and also interlocked at the sides. Verily, we have done well to use the name *paraffin*, not *sinaffin*. They can be joined, in the same plane, at the carboxylic ends and at the sides. To join them at the hydrocarbon ends, the models must be stepped, so as to raise one a layer above the other: this mode of packing is commonly met with in benzene derivatives. The attachment of the hydrogen units is peculiar, different from that adopted in our printed formulae, in that, although they occur in pairs, alternate carbon units carrying each a pair, both are on either one or the other margin of the model. These models, therefore, portray a new method of geometrical analysis, more powerful and intimate perhaps than any yet devised. It is further noteworthy, that although carbon surfaces are exposed, no complete carbon unit of affinity comes to the surface: whereas, in the model of benzene, there are three such affinities on each face.

From the measurements made by Langmuir and by Adam, we are led to conclude that the molecules of a fatty acid spread out upon water in single layers, so arranged that they stand upright, the carboxyl tip

dipping into the water, each upright molecule being closely fitted against its neighbours. The measured thickness of the thinnest black soap film is such that it may well be supposed to consist of two such layers, held upon a belt of water very few molecules thick, one standing upon the upper, the other depending from the lower face of the belt. Interpreting the film in this way, there is no reason to believe in the existence of a complex unit or micelle.

I can overlook sixty of the hundred years since Chevreul's invention. When I first studied chemistry, we were not entirely persuaded of the existence of atoms and were only beginning to form clear conceptions of molecular structure. We did not venture even to dream that we should ever be able to measure and speak with a close approach to certainty of the actual distances between atomic centres, which we now rate at little more than an Ångström unit, one hundred-millionth of a millimetre. Well might Chevreul say: "On doit tendre avec effort à l'infailibilité sans y prétendre": We seem to be near reaching it: though we can still make no claim to infallibility, we are probably far nearer to certainty than Chevreul ever thought possible. The methods which he did so much to make known and appreciated are the methods to which progress is due. As a result, the *bougie stéarique* is no mere illuminant to-day but something at which we can greatly marvel. The chemist can see massed in it wondrously built, tall staircases of atoms, up which the imagination may climb to infinite heights, seeing

..... successive zones
Of several wonder open on some spirit
Flying secure and glad from heaven to heaven.
Paracelsus.

Does the Solar Heat Stream Vary?¹

FIVE notable contributions to the literature of the "solar constant" have come recently from the United States: three, published by the Smithsonian Institution, give the evidence for variation in solar radiations and for the influence of that variation on terrestrial weather; the other two, appearing in the *Monthly Weather Review*, the organ of the Weather Bureau of the United States, contain critical analyses of the radiation statistics.

The first of these papers is an apologia by Prof. C. G. Abbot. He realises that critics have not been convinced hitherto that the fluctuations in the Smithsonian determinations of the "solar constant" represent real variations in the radiation received by the earth, and he sets out to marshal the evidence for variation in the most convincing way.

As a preliminary he narrows discussion by throwing over the earlier observations as too rough for the purpose in view. The paragraph is of such importance that it must be quoted in full:

¹ Washington, Smithsonian Miscellaneous Collections, vol. 77 (1925), No. 5: "Solar Variation and Forecasting," by C. G. Abbot; No. 6: "Solar Radiation and Weather or Forecasting Weather from Observations of the Sun," by H. H. Clayton; No. 7: "Solar Radiation and the Weekly Weather Forecast of the Argentine Meteorological Service," by Guillermo Hoxmark. Washington. *Monthly Weather Review*, July 1925. "On the Question of Day-to-day Fluctuations in the Derived Values of the Solar Constant," by C. F. Marvin. *Smithsonian Solar-constant Values*, by W. W. Kimball.

Some writers mention our data for the past 10 or 15 years as if all were of equal value. Really, to speak in a figure, the Washington data of 1902 to 1907 were prehistoric. As for Mount Wilson results of 1905 to 1908, inclusive, before the invention of the silver disk pyrheliometer, or Fowle's method for estimating total atmospheric humidity... this work is ancient. Excluding altogether July and August 1912, the year of the eruption of the Katmai volcano, all Mount Wilson work of 1909 to 1920 can be classed as medieval. We had then but one station, operating only in summer. We obtained only one determination per day, subject to error from changes of sky transparency and also to errors of computing in the enormous multiplicity of computations used in the reduction of results by Langley's fundamental method. The period from January 1919 to the present is of another order of accuracy and represents the modern period.

It will be seen that it is only the comparatively short series of observations, those since January 1919, made mostly at Harqua Hala in Arizona, and of Mt. Montezuma in Chile, that need be taken seriously as evidence for rapid variations in the solar heat stream. Data for the greater part of this period, August 1920 to November 1924, have been published in a convenient form by the Smithsonian Institution (Misc. Collections, vol. 77, No. 3, Feb. 1925).