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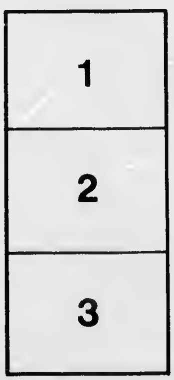
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[From the American Journal of Science, Vol. XXIII, February, 1882.]

# CELESTIAL CHEMISTRY FROM THE TIME OF NEWTON.

By T. Sterry Hunt, LL.D., F.R.S.

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[FROM THE AMERICAN JOURNAL OF SCIENCE, VOL. XXIII, FEBRUARY, 1882.]

# CELESTIAL CHEMISTRY FROM THE TIME OF NEWTON.

BY T. STERRY HUNT, LL.D., F.R.S.*

THE late W. Vernon Harcourt, in 1845,† called attention to the remarkable perception of great chemical truths which is apparent in the Queries appended to the third book of Newton's *Optics*, as well as in his Hypothesis touching Light and Color. With regard to the latter, Harcourt then remarked, "it has, I think, scarcely been quoted, except by Dr. Young, and its existence is but little known, even among the best-informed scientific men." The essay in question was read before the Royal Society, December 9th and 16th, 1675, but remained unpublished till 1757, when Birch, at that time secretary to the Society, printed it, not without verbal inaccuracies, in the third volume of his History of the Royal Society; a work intended to serve as supplement to the Philosophical Transactions up to that date. In 1846, at the suggestion of Harcourt, the Hypothesis of Newton was again printed in the L. E. and D. Philosophical Magazine (volume xxix), and it subsequently appeared in the Appendix to the first volume of Brewster's Memoirs of Sir Isaac Newton, in 1855.

The time has come for further inquiries into the science of Newton, and I shall endeavor to show that a careful examina-

* Read before the Cambridge (England) Philosophical Society, November 28, 1881, and reprinted from its Proceedings.

† L. E. and D. Philos. Magazine, III, xxviii, 106 and 478; also xxix, 185.

tion of the writings of our great Natural Philosopher, in the light of the scientific progress of the last generation, renders still more evident the wonderful prevision of him who already, two centuries since, had anticipated most of the recent speculations and conclusions regarding cosmic chemistry.

As an introduction to the inquiries before us, and in order to show the real significance of the speculations of Newton, it will be necessary to review, somewhat at length, the history of certain views enunciated almost simultaneously by the late Sir Benjamin Brodie, of Oxford, and the present writer, and subsequently developed and extended by the latter. In part I of his Calculus of Chemical Operations, read before the Royal Society, May 3, 1866, and published in the Philosophical Transactions for that year, Brodie was led to assume the existence of certain ideal elements. These, he said "though now revealed to us through the numerical properties of chemical equations only as *implicit and dependent existences*, we cannot but surmise may sometimes become, or may in the past have been, *isolated and independent existences.*" Shortly after this publication, in the spring of 1867, I spent several days in Paris with the late Henri Sainte-Claire Deville, repeating with him some of his remarkable experiments in chemical dissociation, the theory of which we then discussed in its relations to Faye's solar hypothesis. From Paris, in the month of May, I went, as the guest of Brodie, for a few days to Oxford, where I read for the first time and discussed with him his essay on the Calculus of Chemical Operations, in which connection occurred the very natural suggestion that his ideal elements might perhaps be liberated in solar fires, and thus be made evident to the spectroscope. I was then about to give, by invitation, a lecture before the Royal Institution on The Chemistry of the Primeval Earth, which was delivered May 31, 1867. A stenographic report of the lecture, revised by the author, was published in the Chemical News of June 21, 1867, and in the Proceedings of the Royal Institution. Therein, I considered the chemistry of nebulæ, sun and stars in the combined light of spectroscopic analysis and Deville's researches on dissociation, and concluded with the generalization that the "breaking-up of compounds, or dissociation of elements, by intense heat is a principle of universal application, so that we may suppose that all the elements which make up the sun, or our planet, would, when so intensely heated as to be in the gaseous condition which all matter is capable of assuming, remain uncombined; that is to say, would exist together in the state of chemical elements; whose further dissociation in stellar or nebulous masses may even give us evidence of matter still more elemental than that revealed in the experiments of the laboratory, where we can only conjecture the compound nature of many of the so-called elementary substances."

The importance of this conception, in view of subsequent discoveries in spectroscopy and in stellar chemistry, has been well set forth by Lockyer in his late lectures on Solar Physics,* where, however, the generalization is described as having been first made by Brodie in 1867. A similar but later enunciation of the same idea by Clerk-Maxwell is also cited by Lockyer. Brodie, in fact, on the 6th of June, one week after my own lecture, gave a lecture on Ideal Chemistry before the Chemical Society of London, published in the Chemical News of June 14th, in which, with regard to his ideal elements, in further extension of the suggestion already put forth by him in the extract above given from his paper of May 6, 1866, he says "we may conceive that in remote ages the temperature of matter was much higher than it is now, and that these other things [the ideal elements] existed in the state of perfect gases—separate existences—uncombined." He further suggested, from spectroscopic evidence, that it is probable that "we may one day, from this source have revealed to us independent evidence of the existence of these ideal elements in the sun and stars."

During the months of June and July, 1867, I was absent on the continent, and this lecture of Brodie's remained wholly unknown to me until its republication in 1880, in a separate form, by its author,† with a preface, in which he pointed out that he had therein suggested the probable liberation of his ideal elements in the sun, referring at the same time to his paper of 1866, from which we have already quoted the only expression bearing on the possible independence of these ideal elements somewhere in time or in space.

The above statements are necessary in order to explain why it is that I have made no reference to Sir Benjamin Brodie on the several occasions on which, in the interval between 1867 and the present time, I have reiterated and enforced my views on the great significance of the hypothesis of celestial dissociation as giving rise to forms of matter more elemental than any known to us in terrestrial chemistry. The conception, as at first enunciated in somewhat different forms alike by Brodie and myself, was one to which we were both naturally, one might say inevitably, led by different paths from our respective fields of speculation, and which each might accept as in the highest degree probable, and make, as it were, his own. I write, therefore, in no spirit of invidious rivalry with my honored and lamented friend, but simply to clear myself from the charge, which might otherwise be brought against me, of

* Nature, August 25, 1881, vol. xxiv, p. 396.

† Ideal Chemistry, a Lecture. Macmillan, 1880.

having on various occasions within the past fourteen years, put forth and enlarged upon this conception without mentioning Sir Benjamin Brodie, whose only publication on the subject, so far as I am aware, was his lecture of 1867, unknown to me until its reprint in 1880.

It was at the grave of Priestley, in 1874, that I for the second time considered the doctrine of celestial dissociation, commencing with an account of the hypothesis put forward by F. W. Clarke, of Cincinnati, in January, 1873,* to explain the growing complexity which is observed when we compare the spectra of the white, yellow and red stars; in which he saw evidence of a progressive evolution of chemical species, by a stoichiogenic process, from more elemental forms of matter. I then referred to the further development of this view by Lockyer in his communication to the French Academy of Sciences in November of the same year, wherein he connected the successive appearance in celestial bodies of chemical species of higher and higher vapor-densities with the speculations of Dumas and Pettenkofer as to the composite nature of the chemical elements.† I then quoted from my lecture of 1867 the language already cited, to the effect that dissociation by intense heat in stellar worlds might give us more elemental forms of matter than any known on earth, and further suggested that the green line in the spectrum of the solar corona, which had been supposed to indicate a hitherto unknown substance, may be due to a "more elemental form of matter, which, though not seen in the nebulæ, is liberated by the intense heat of the solar sphere, and may possibly correspond to the primary matter conjectured by Dumas, having an equivalent weight one-fourth that of hydrogen." The suggestion of Lavoisier, that "hydrogen, nitrogen, and oxygen, with heat and light, might be regarded as simpler forms of matter from which all others are derived," was also noticed in connection with the fact that the nebulæ, which we conceive to be condensing into suns and planets, have hitherto shown evidences only of the presence of the first two of these elements, which, as is well-known, make up a large part of the gaseous envelope of our planet, in the forms of air and aqueous vapor. With this, I connected the hypothesis that our atmosphere and ocean are but portions of the universal medium which, in an attenuated form, fills the interstellary spaces; and further suggested as "a legitimate and plausible speculation," that "these same nebulæ and their resulting worlds may be evolved by a process of chemical condensation from this universal atmosphere, to which they would sustain a relation some-

* Clarke, "Evolution and the Spectroscope," Popular Science Monthly, New York, vol. ii, p. 32.

† Lockyer, Comptes Rendus, November 3, 1873.

what analogous to that of clouds and rain to the aqueous vapor around us."*

These views were reiterated in the preface to a second edition of my Chemical and Geological Essays, in 1878, and again before the British Association for the Advancement of Science at Dublin,† and before the French Academy of Sciences in the same year.‡ They were still further developed in an essay on the Chemical and Geological Relations of the Atmosphere, published in this Journal for May, 1880, in which attention was called to the important contribution to the subject by Mr. Lockyer in his ingenious and beautiful spectroscopic studies, the results of which are embodied in his "Discussion of the Working Hypothesis that the so-called Elements are Compound Bodies," communicated to the Royal Society, December 12, 1878. It was then remarked that the already noticed "speculation of Lavoisier is really an anticipation of that view to which spectroscopic study has led the chemists of to-day;" while it was said that the hypothesis put forth by the writer in 1874, "which seeks for a source of the nebulous matter itself, is perhaps a legitimate extension of the nebular hypothesis."

To show the connection of the above views with the philosophy of Newton, it now becomes necessary to give some account of the conception of the universal distribution of matter throughout space, both as regards its dynamical relations and its chemical composition. Passing over the speculations of the Greek physiologists, we come to the controversies on this subject in the seventeenth century, and find, in apparent opposition to the plenum maintained by Descartes and his followers, the teaching of Newton that "the heavens are void of all sensible matter." This statement is, however, qualified elsewhere by his assertion, that "to make way for the regular and lasting movements of the planets and comets, it is necessary to empty the heavens of all matter, except perhaps some very thin vapors, steams and effluvia arising from the atmospheres of the earth, planets and comets, and from such an exceedingly rare etherial medium as we have elsewhere described," etc. (*Optics*, Book III, Query 28).

In order to understand fully the views of Newton on this subject, it is necessary to compare carefully his various utterances, including the Hypothesis, in 1675, the first edition of the *Principia*, in 1687, the second edition, in 1713, and the various editions of the *Optics*. This work appeared in 1704, the third book, with its appended queries, having, according to its author's preface, been "put together out of scattered papers"

* A Century's Progress in Theoretical Chemistry, being an address at Northumberland, Penn., July 31, 1874; Amer. Chemist, vol. v, pp. 46–61, and Pop. Science Monthly, vi, p. 420.

† Nature, Aug. 29, 1878, vol. xviii, p. 475.

‡ Comptes Rendus, Sept. 23, 1878, vol. xxxviii, p. 452.

subsequent to the publication of the first edition of the *Principia.* The Latin translation of the *Optics*, by Dr. Clarke, which was published in 1706, and the second English edition, in 1718, contain successive additions to these queries, which are indicated in the notes to Horsley's edition of the works of Newton, and are important in this connection. From a collation of all these, we learn how the conceptions of the Hypothesis took shape, were re-inforced, and in great part incorporated in the *Principia.*

In the Hypothesis, he imagines "an etherial medium much of the same constitution with air, but far rarer, subtler, and more elastic." "But it is not to be supposed that this medium is one uniform matter, but composed partly of the main phlegmatic body of ether, partly of other various etherial spirits, much after the manner that air is compounded of the phlegmatic body of air intermixed with various vapors and exhalations." Newton further suggests in his Hypothesis that this complex spirit or ether, which, by its elasticity, is extended throughout all space, is in continual movement and interchange. "For nature is a perpetual circulatory worker, generating fluids out of solids, and solids out of fluids, fixed things out of volatile, and volatile out of fixed, subtile out of gross, and gross out of subtile; some things to ascend and make the upper terrestrial juices, rivers, and the atmosphere, and by consequence others to descend for a requital to the former. And as the earth, so perhaps may the sun imbibe this spirit copiously, to conserve his shining, and keep the planets from receding farther from him; and they that will may also suppose that this spirit affords or carries with it thither the solary fuel and material principle of life, and that the vast etherial spaces between us and the stars are for a sufficient repository for this food of the sun and planets."

The language of this last sentence, in which his late biographer, Sir David Brewster, regards Newton as "amusing himself with the extravagance of his speculations," at which "we may be allowed to smile,"* was not apparently regarded as unreasonable by its author when, more than ten years later, he quoted it in the postscript of his letter to Halley, dated Cambridge, June 20, 1686. The views therein contained, with the single exception of the suggestion regarding gravitation, have not wanted advocates in our own time, and many of them were embodied in the *Principia*, which Newton was then engaged in writing.

But this was not all: Newton saw in the cosmic circulation and the mutual convertibility of rare and dense forms of matter a universal law, and rising to a still bolder conception, which

* Brewster's Memoirs of Newton, vol. i, pp. 121 and 404.

completes his Hypothesis of the Universe, adds: "Perhaps the whole frame of nature may be nothing but various contextures of some certain etherial spirits or vapors, condensed, as it were, by precipitation, much after the same manner that vapors are condensed into water, or exhalations into grosser substances, though not so easily condensible; and after condensation wrought into various forms, at first by the immediate hand of the Creator, and ever since, by the power of nature, which, by virtue of the command 'increase and multiply,' became a complete imitator of the copy set her by the great Protoplast. Thus, perhaps may all things be originated from ether."

If now we look to the third book of the *Principia*, we shall find in proposition 41 the remarkable chemical argument by which Newton was led to regard the interstellary ether as affording "the material principle of life" and "the food of planets." Considering the exhalations from the tails of comets, he supposes that the vapors thus derived, being rarified, dilated, and spread through the whole heavens, are by gravity brought within the atmospheres of the planets, where they serve for the support of vegetable life. Inasmuch, moreover, as all vegetation is supported by fluids, and subsequently, by decay is, in part, changed into solids, by which the mass of the earth is augmented, he concludes that if these essential matters were not supplied from some external source, they must continually decrease, and at last fail. This vital and subtile part of our atmosphere, so important, though small in amount, he then supposed might come from the tails of comets.*

This appeared in the first edition of the *Principia*, in 1687. It was not until later that the conception of exhalations from other celestial bodies took shape in the mind of Newton, as we may learn from the *Optics*. Thus, in the first edition of this work, in Query 11, the sun and fixed stars are spoken of as

*"Vapor enim in spatiis illis liberrimis perpetuò rarescit, ac dilatatur. Quâ ratione fit ut cauda omnis ad extremitatem superiorem latior sit quám juxta capita cometae. Eâ autem rarefactione vaporem perpetuò dilatatum diffundi tandem et spargi par coelos universos, deinde paulatim in planetas per gravitatem suam attrahi et cum eorum atmosphaeris misceri, rationi consentaneum videtur. Nam quemadmodum maria ad constitutionem Terrae hujus omnino requiruntur, idque ut ex iis per calorem Solis vapores copiosè satis excitentur, qui vel in nubes coacti decidant in pluviis, et Terram omnem ad procreationem vegetabilium irrigent et nutriant; vel in frigidis montium verticibus condensati (ut aliqui cum ratione philosophantur) decurrant in fontes et flumina: sic ad conservationem marium et humorum in planetis requiri videntur cometae, ex quorum exhalationibus et vaporibus condensatis, quicquid liquoris per vegetationem et putrefactionem consumitur et in Terram aridam convertitur, continuò suppleri et refici possit. Nam vegetabilia omnia ex liquoribus omninò crescunt, dein magnâ ex parte in Terram aridam per putrefactionem abeunt, et limus ex liquoribus putrefactis perpetuò decidit. Hinc moles Terrae aridae indies augetur, et liquores, nisi aliunde augmentum sumerent, perpetuò decrescere deberent, ac tandem deficere. Porro suspicor spiritum illum, qui aëris nostri pars minima est, sed subtillissima et optima, et ad rerum omnium vitam requiritur, ex cometis praecipue venire."—*Newton*, *Principia*, lib. III, prop. XLI.

great earths, intensely heated, and surrounded with dense atmospheres which, by their weight, condense the exhalations arising from these hot bodies. To this Query is added, in 1706, the suggestion that the weight of such an atmosphere "may hinder the globe of the sun from being diminished except by the emission of light;" while in the second English edition, in 1718, we find a further addition, in the words "and a very small quantity of vapors and exhalations." A similar change of view appears in the Query now numbered 28, wherein we read of "places [almost] destitute of matter," and also that "the sun and planets gravitate towards each other without [dense] matter between." In these quotations, the two words in brackets are wanting in the edition of 1706, and first appear in that of 1718; while the language which we have in a previous page quoted from this same Query is found in the edition of 1706.

The Queries now numbered 17–24, appeared for the first time in the edition of 1718, and herein we find, in 18, the etherial medium spoken of as being "by its elastic force expanded through all the heavens." Of this medium, "which fills all space adequately," he asks, "may not its resistance be so small as to be inconsiderable," and scarcely to make any sensible alteration in the movements of the planets?* This complex ether of the interstellary space was thus, in the opinion of Newton, made up in part of matter common to the planetary and stellar atmospheres, the origin and importance of which is concisely stated in the paragraph which appears for the first time in 1713, in the second edition of the *Principia*, in the third book, at the end of proposition 42, here much augmented. In this statement, which serves to supplement and complete that already made in 1687, in proposition 41, we read, that the vapors which arise alike from the sun, the fixed stars and the tails of comets, may by gravity fall into the atmospheres of the planets, and there be condensed, and pass into the form of salts. sulphurs, (*id est*, combustible matters,) tinctures, clay, sand, coral and other terrestrial substances.†

The conception of Newton, who, while rejecting alike the plenum of the Cartesians, with its vortices, and an absolute vacuum, imagined space to be filled with an exceedingly attenuated matter, through which a free circulation of gaseous substances might take place between distant worlds, has found

* Compare this with Prop. x, Book III of the Principia.

† "Vapores autem, qui ex Sole et stellis fixis et caudis cometarum [illegible]tur, incidere possunt per gravitatem suam in atmosphaeras planetarum. et ibi condensari et converti in aquam et spiritos humidos, et subinde per lentem calorem in sales, et sulphura, et tincturas. et limum, et lutem. et argillam, et arenam, et lapides, et coralla, et substantias alias terrestres paulatim migrare."—*Newton*, *Principia*, lib. III, prop. XLII.

favor among modern thinkers, who seem to have been ignorant of his views. Sir William Grove in 1842, suggested that the medium of light and heat may be "a universally diffused matter," and subsequently, in 1843, in the chapter on Light, in his *Essay on the Correlation of Physical Forces*, concluded with regard to the atmospheres of the sun and the planets, that there is no reason "why these atmospheres should not be, with reference to each other, in a state of equilibrium. Ether, which term we may apply to the highly attenuated matter existing in the interplanetary spaces, being an expansion of some or all of these atmospheres, or of the more volatile portions of them, would thus furnish matter for the transmission of the modes of motion which we call light, heat, etc.; and possibly minute portions of the atmospheres may, by gradual accretions and subtractions, pass from planet to planet, forming a link of material communication between the distant monads of the universe." Subsequently, in his address as President of the British Association for the Advancement of Science, in 1866, Grove further suggested that this diffused matter may become a source of solar heat, "inasmuch as the sun may condense gaseous matter as it travels in space, and so heat may be produced."

Humboldt, also, in his *Cosmos*, considers the existence of a resisting medium in space, and says "of this impeding etherial and cosmical matter," it may be supposed that it is in motion, that it gravitates, notwithstanding its great tenuity, that it is condensed in the vicinity of the great mass of the sun, and that it may include exhalations from comets; in which connection he quotes from the 42nd proposition of the third book of the *Principia*. He further speaks comprehensively of "the vaporous matter of the incommensurable regions of space, whether, scattered without definite limits, it exists as a cosmical ether, or is condensed in nebulous masses and becomes comprised among the agglomerated bodies of the universe."* Humboldt also cites in this connection a suggestion made by Arago in the *Annuaire du Bureau des Longitudes* for 1842, as to the possibility of determining, by a comparison of its refractive power with that of terrestrial gases, the density of "the extremely rare matter occupying the regions of space."†

In 1854, Sir William Thomson published his note on the Possible Density of the Luminiferous Ether,‡ wherein he remarks "that there must be a medium of material communication throughout space to the remotest visible body, is a fundamental conception of the undulatory theory of light. Whether

* Cosmos, Otté's translation, Harper's ed., vol. i, pp. 82, 86.

† Ibid., vol. iii, p. 40.

‡ Trans. Roy. Soc. Edinburgh, vol. xxi, part 1; and Phil. Mag., 1855, vol. ix, p. 36.

or no this medium is (as appears to me most probable) a continuation of our own atmosphere, its existence cannot be questioned." He then attempts to fix an inferior limit to the density of the luminiferous medium in interplanetary space by considering the mechanical value of sunlight, as deduced from the value of solar radiation and the mechanical equivalent of the thermal unit. He concludes "that the luminiferous medium is enormously denser than the continuation of the terrestrial atmosphere would be in interplantary space if rarified according to Boyle's law always, and if the earth were at rest in a state of constant temperature, with an atmosphere of the actual density at its surface." The earth itself in moving through space "cannot displace less than 250 pounds of matter."

In 1870, W. Mattieu Williams published his very ingenious work entitled The Fuel of the Sun, in which, apparently without any knowledge of what had been written before with regard to an interstellary medium, he attempts to find therein the source of solar heat—the "solary fuel" of Newton. To quote his own language, "the gaseous ocean in which we are immersed is but a portion of the infinite atmosphere that fills the whole solidity of space, that links together all the elements of the universe, and diffuses among them light and heat, and all the other physical and vital forces which heat and light are capable of generating" (loc. cit. p. 5).

Since the days of Newton, however, no one had hitherto considered the interstellary matter from a chemical point of view. In 1874, as already shown, the writer had, in extension of the conception of Humboldt that its condensation gives rise to nebulæ, ventured the suggestion that from an etherial medium having the same composition as our own atmosphere, the chemical elements of the sun and the planets have been evolved, in accordance with the views of Brodie, Clarke, and Lockyer, by a stoichiogenic process; so that in the language of Newton's Hypothesis, "all things may be originated from ether."

It was not, however, until 1878, that, from a consideration of the chemical processes which have gone on at the earth's surface within recorded geological time, I was led to another step in this inquiry. That all the de-oxidized carbon found in the earth's crust in the forms of coal and graphite, as well as that existing in a diffused state, as bituminous or carbonaceous matter, has come, through vegetation, from atmospheric carbonic acid, appears certain. To the same source we must ascribe the carbonic acid of all the limestones which, since the dawn of life on our earth, have been deposited from its waters. It is through the sub-aërial decay of crystalline silicated rocks, and the direct formation of carbonate of lime, or of carbonates of magnesia and alkalies which have reacted on the calcium-salts of the pri meval ocean, that all limestones and dolomites have been generated. These, apart from the coaly matter, hold, locked up and withdrawn from the aërial circulation, an amount of carbonic acid which may be probably estimated at not less than 200 atmospheres equal in weight to our own. That this amount, or even a thousandth part of it, could have existed at any one time in our terrestrial atmosphere since the beginning of life on our planet is inconceivable, and that it could be supplied from the earth's interior is an hypothesis equally untenable.

I was therefore led to admit for it an extra-terrestrial source, and to maintain that the carbonic acid has thence gradually come into our atmosphere to supply the deficiencies created by chemical processes at the earth's surface. Since similar processes are even now removing from our atmosphere this indispensable element, and fixing it in solid forms, it follows that except volcanic agency, which can only restore a portion of what was primarily derived from the atmosphere, there are on earth, besides organic decay, only the artificial processes of human industry which can furnish carbonic acid; so that but for a supply of this gas from the interstellary spaces now, as in the past, vegetation, and consequently animal life itself, would fail and perish from the earth, for want of this "food of planets."

Such were the conclusions, based on an induction from the facts of modern chemistry and geology, which I enunciated in my papers in 1878 and 1880, already quoted in the first part of this essay. I was at that time unacquainted with the Hypothesis of Newton, and with his remarkable reasoning contained in the 41st proposition of the third book of the *Principia*, in which he, so far as was possible with the chemical knowledge of his time, anticipated my own argument, and showed how and in what manner the interstellary ether may really afford the "food of planets," and, in a sense, "the material principle of life."

I have thus endeavored to bring before the Philosophical Society of Cambridge, a brief history of the development of this conception of an interstellary medium, and to show that the thought of two centuries has done little more than confirm the almost forgotten views of Newton. It is with feelings of peculiar gratification that I have been able to indite these pages within the very walls of the college in which our great philosopher lived and labored, and where, combining all the science of his time with a foresight which seems well-nigh divine, he was enabled, in the words of the poet, "to think again the great thought of the creation."