TWO

Henry Eliot 1827

LECTURES ON COMETS,

BY PROFESSOR WINTHROP,

ALSO,

AN ESSAY ON COMETS,

BY A. OLIVER, JUN. ESQ.

WITH

SKETCHES OF THE LIVES OF PROFESSOR WINTHROP AND MR. OLIVER.

LIKEWISE,

A SUPPLEMENT,

RELATIVE TO THE PRESENT COMET OF 1811.

BOSTON:

PUBLISHED BY W. WELLS AND T. B. WAIT AND CO.

T. B. Wait and Co. Printers.

1811.

PREFACE.

The intrinsic merit of the dissertations contained in this volume, has long induced a wish for their re-publication, among those whose attention has been directed to the subjects therein discussed.

The recent appearance of a brilliant comet has more especially prompted the publishers to give a new edition of these valuable papers at the present time.

The crude and fantastic ideas occasionally connected with comets, and the sallies of imagination to which they, not unfrequently, give rise, have thrown an air of levity on the subject, in some degree unfavourable to a serious investigation. But men of sense and reflection, while not unfriendly to an innocent play of fancy, well understand its limits, and will not suffer any casual associations from that source to prevent or impede a just and sober extension of their inquiries on any topic of interest. There can be no apprehension, therefore, that the contents of this volume will be considered as unworthy of engaging a rational curiosity and deliberate examination.

Those, whose views of the subject are transient and unsettled, will find in this summary a condensed exhibition of what has been scientifically demonstrated relative to this interesting portion of the universe, and the most approved conjectures in regard to what may still be considered s problematical.

That class of readers, whose intellectual survey is more exact, will not think it unprofitable to revise the details on which are founded the results which they may have embraced. All, it may be hoped, will regard with complacency this renewed diffusion of performances, honourable to the authors and to our country.

It was intended to have completed this re-impression at an earlier day. The delay that has occurred, has been caused by a wish to render the work more valuable to the reader. Opportunity has been given to procure a detailed account of the present comet, from European observations, as well as from domestic sources. This account will be found in the Supplement, with incidental remarks connected with the subject. From the friend who furnished those additions, the publishers have also been favoured with sketches of the lives and characters of the learned and estimable men, whose writings they have copied. These biographical notices were considered as a proper appendage to the volume.

If, by this publication, the editors and those who have co-operated with them, should in any degree promote a taste and spirit for astronomical science and philosophical research, it will be a source of gratification; for they are persuaded that pursuits of this description, while they are no injurious impediment to occupations of more immediate interest, have a decided tendency to improve the individual, and to elevate the national character.

Boston, Dec. 1811.

SKETCHES

OF THE LIFE AND WRITINGS OF THE LATE

PROFESSOR WINTHROP.

JOHN WINTHROP, L.L.D. F.R.S. author of the Lectures on Comets republished in this volume, was descended, in the fourth generation, from *John Winthrop*, first governor of Massachusetts. He was born in Boston, December 19, 1714. His father was Adam Winthrop, Esq. one of the council, whose father and grandfather of the same name had sustained the same honourable office. Of the earliest years of Mr. Winthrop, we have no particular information. There was a spirit of literature in the family, a portion of which probably gave an early bias to his mind, and directed his pursuits.* He was educated at Harvard College, and received his bachelor's degree in 1732. Such was his reputation for mathematical learning, that in 1738, he was appointed

* The eldest son of governor Winthrop was eminent for philosophical knowledge, was one of the founders of the Royal Society, and was specially invited "to take upon himself the charge of being the chief correspondent in the West, as Sir Philiberto Vernalti was in the East Indies."—His son and grandson manifested similar dispositions. The latter was also member of the Royal Society, and died in England, 1747.

Hollis Professor of Mathematics and Natural Philosophy in that Seminary, in place of Mr. Greenwood, who was the first professor on that foundation. The diligence, zeal, and ability, with which he discharged the interesting duties of his office, are abundantly testified by those who have written of his character; and are well recollected by many still surviving, who received the benefit of his instruction. In 1740, two years only after his induction into office, he observed the transit of Mercury over the sun's disk. This phenomenon, which is of peculiar importance in determining the theory of that planet, had engaged the attention of astronomers since the days of Kepler. That great man thought he had seen it in 1607, but afterwards discovered his mistake, and found, that what he had taken for Mercury was one of the spots on the solar disk. It was first observed by Gassendi, in 1631. In 1651, it was seen by no person but Jeremiah Shakerly, an Englishman, who made a voyage to Surat, expressly for the purpose of observing it; and there died, an honourable victim to his zeal for astronomical science.

Professor *Winthrop*'s observations were made with accuracy. They were transmitted to the Royal Society, by whom honourable notice was taken of them and of the observer. They were published in the 42d vol. of the Transactions of the Society; and respectful mention is also made of them in the Memoirs of the Royal Academy of Sciences at Paris.

In 1755, he published a Lecture on Earthquakes, composed and delivered in consequence of the memorable earthquake of that year. This performance produced some strictures from the Rev. Dr. Prince, of Boston, who was apprehensive that an attempt to explain phenomena of such tremendous import, had a tendency to impair the religious views and impressions which they have a tendency to inspire. The professor replied to these remarks in 1756; and with temperate and rational dignity defended philosophical discussion from any imputations of impiety or irreverence. His next publication was the two Lectures on *Comets* now republished. From this specimen, his talent for investigation, his clear, perspicuous, and instructive method of writing will be perceived by the attentive reader. They give a summary history of opinions, and a condensed view of the state of knowledge on that subject.*

* Such was the interest excited by the expectation of the Comet of 1759, that some astronomers, M. Messier, particularly, were sedulously employed in looking for it, a year and a half before it appeared. Dr. Winthrop first saw it April 3, after it had passed its perihelion. M. Messier discovered it in its descent to the sun, on the 20th January, and observed it in secret till February 14, when it was nearly in conjunction with the sun. This studied secrecy it seems was to vex *DeLisle*, who it is said was fond of accumulating astronomical treasures, and reserving them to himself. Both these *savans*, and indeed all the astronomers of the age, were anticipated by a Saxon peasant, *Palitzch*, near Dresden, who discovered the Comet December 25, 1758. Montucla gives an interesting account of this rural philosopher, who had acquired a considerable degree of mathematical knowledge, had a collection of instruments, and mingled scientific investigations, and the study of natural history, with his agricultural labours.

Professor Winthrop's attention was next to be directed to a celestial appearance of great scientific interest, the passage of the planet *Venus* over the sun. This phenomenon is of rare occurrence. It had at that time been observed by only two persons, Jeremiah Horrox, and his friend William Crabtree, both of the west of England, and by them only about 35 minutes. This was in 1639. It was known to astronomers, that another opportunity would occur for the observation on the 6th of June 1761. Besides the rare occurrence of the phenomenon, its important use and application, for determining the parallax of the sun, rendered it of peculiar importance that it should be accurately observed. In regard to these transits, to use the language of professor Winthrop, in one of his lectures, "on account of their rarity alone, they must afford " an exquisite entertainment to an astronomical taste. " But this is not all. There is another circumstance " which strongly recommends them; they furnish the " only adequate means of solving a most difficult " problem, that of determining the true distance of the " sun from the earth. This has always been a principal object of astronomical inquiry; without this, " we can never ascertain the true dimensions of the " solar system, and the several orbs of which it is composed, nor assign the magnitudes and densities of " the sun, the planets, and comets; nor of consequence, attain a just idea of the grandeur of the " the works of God." This use of the transits of Venus, was first pointed out by Dr. Halley; and as the period approached, a lively interest was excited to comply with the earnest wish which he had expressed, that observers might be stationed in different parts of the earth, in order that some of them might be sure to succeed. The governments of England, France, Russia, Denmark, and Sweden, were all attentive to the subject. Professor Winthrop observed the transit at St. Johns, Newfoundland; performing the voyage, with his assistants, in the Province sloop, and at the expense of the Province. This literary expedition was in pursuance of a resolve of the general court, at the recommendation of governor Barnard. "It was a public act for the benefit of science," says one of the professor's foreign correspondents, "that did your Province great honour." Of this interesting voyage he published a relation soon after his return. Newfoundland, he remarks, was the only British plantation in which an observation of the transit could be made, and indeed the most western part of the earth, where the end of the transit could be observed; for it was to happen before the sun would be risen to any other part of America, except the savage coast of Labrador.

The British government had announced an intention of sending some competent observer to North America. But were diverted from the plan, as Montucla relates, by *DeLisle's* chart, prepared for the purpose of exhibiting all the places on the globe in which the transit could be observed to advantage. The spontaneous interest manifested in Massachusetts to this object, was thus rendered by this inadvertence more critical and important.

In 1765, professor Winthrop published an account of several fiery meteors seen in North America; and in 1766 he wrote a paper entitled *Cogitata De Cometis*. It was communicated to the Royal Society, by Dr. Franklin, in the succeeding year, and was soon afterwards printed separately in a pamphlet form in London. Professor Winthrop had not long before been elected a member of that learned body. The degree of L.L.D. he received from the University of Edinburgh, and from his own College. To his treatise is prefixed the following neat inscription.

ILLUSTRISSMÆ
SOCIETATI REGIAE,
ob
Summum in se collatum honorem,
cooptationem scil. in eorum sodalitium,
Hanc qualemcunque dissertationem,
ea qua par est observantia,
D. D. C. Q.
JOHANNES WINTHROP,
Apud Cantab. Nov. Ang.
Math. et Phil. Prof. Hollisianus.
7 Maii 1766.

It is a learned and ingenious attempt to demonstrate the theory, suggested by Sir Isaac Newton, to explain the ascent of the tails of comets. "Ascensum caudæ cometicæ—aliquantulum illustrare aggressi sumus," is the modest language of the author. The paper contains five Problems, with dependent Scholia and Corollaries. It investigates the limit of attraction between comets and the sun, and the laws of motion and direction by which an elastic fluid or vapour, arising from the head of a comet, would be governed. In the 3d Corollary, under the 5th Problem, the author deduces the masses and densities of comets from the observed breadth of the coma on the side next the sun. He considers this investigation as new. "En! "specimen calculi, hactenus, quod sciam, intacti: "quod curiosis naturæ scrutatoribus haud ingratum "fore spero."—By this method, he infers, that the density of the comet of 1665 was to the density of the earth as 3·50 to 1; and that of the comet of 1682, as 5 to 11; and suggests an analogy, in this respect, between comets and planets; that the densities are greater in proportion to their nearness to the sun. M. Bailly, in his history of astronomy, notices this part of Professor Winthrop's paper, and observes that the law of Newton, that the bodies nearest the sun have the greatest density, can only serve to compare comets with one another. "When we compare their den-"sity with that of the planets," says M. B. "it is "more natural to be regulated by their elongations; "and then the law of Newton would indicate, that "comets which wander to such immense distance "must be of inconsiderable mass."

The prevailing opinion, among modern physico-astronomers, seems to be, that comets, though having a solid nucleus, are of inconsiderable density, and contain but a small quantity of matter.

It has never been determined whether comets have a rotation on their axes, though this has generally been presumed from their ascertained resemblances, in other particulars, to the planets, which are known to have such a motion. Professor Winthrop in his *Cogitata*, in explaining the curved appearance of the tails of comets, which is occasionally manifested, has this remark, that as no incurvation or deviation from opposition to the sun is perceived, but what may arise from the progressive motion of the head round the sun, it appears probable that comets do not revolve on their axes.

A complete analysis of this performance is not intended in this place. From what has been mentioned it will probably be considered by the intelligent, as meriting attention in all inquiries on the subject to which it relates

The observations on the transit of Venus in 1761, when collected and compared, were not so satisfactory as had been anticipated. There was a perplexing uncertainty from the wide difference in the results of M. Mason's observations, made at the Cape of Good Hope, and those of M. Pingré, made on an island in the Indian Ocean. By the former, the sun's parallax was 8″, 50. by the latter, 10″, 2. Mr. Short, of London, by a careful collation of all the observations, made the mean result of the sun's parallax, 8″, 545. by the internal contacts, and by the external contact 8″, 551.

From this determination, says Doctor W. "I find the sun's parallax at his mean distance from the earth to be 8″, 68." But in De la Lande's Astronomy, 1st edition, published in 1764, it is placed at 9″. From these uncertainties a renewed interest was manifested, to secure the best possible observations of the transit of the same planet on June 3, 1769. It was partly the object of Cook's first voyage, and was observed to advantage at Otaheite. Professor Winthrop delivered two Lectures on the subject, in the College Chapel, in March of that year, which were soon afterward published. In these Lectures the circumstances and theory of the phenomenon, and its important use and application in astronomy, are fully and clearly expressed. "It can never happen," he observes, "above "twice in any century, in others but once, and in "some centuries it cannot happen at all.—When this "of June next is past, the present race of mortals "may take their leave of these transits; for there is "not the least probability that any one who sees this, "will ever see another."—With this impression he affixed this motto to the Lectures; *Agite, mortales! et oculos in Spectaculum vertite, quod hucusque spectaverunt perpaucissimi, spectaturi iterum sunt nulli.**—He concludes by wishing all curious observers a serene sky. In this he was gratified. But it was only the beginning of the transit that could be observed here, the end being after sun-set. Doctor W. in conformity to

* "The next transit will be on the 9th of Dec. in the year 1874; which will be invisible here. There will be another in 8 years after. The next, after that, will be in 2004. Thus the whole 20th century will pass without a transit." Winthrop's Rel. and Lect.

hucusque

the wishes of Mr. Maskelyne, Astronomer Royal at Greenwich, would have gone with alacrity to Lake Superior, to observe this transit, the nearest place to the Atlantic Settlements where the beginning and end were visible; but his state of health forbade the undertaking; and he was obliged, as he says, with great mortification, to decline all thoughts of it. This disappointment, however, was less to be regretted, when it was found that two complete observations of the whole transit were made on the American Continent, one at Hudson's Bay, the other in California. The entire duration of this transit was also observed at two places in the north of Europe.* The result of a laborious calculation made by De la Lande, Lexell, Euler, and other able astronomers, gave 8″ 5. 8″ 7, and 8″ 8, for the parallax of the sun. *La Lande*, has adopted 8″ 6 for that parallax, or as the measure of the angle which the semi diameter of the earth subtends, viewed from the sun: making the

* This transit was also observed by Dr. Rittenhouse, Ewing, Smith, Shippen, and others in Pennsylvania, and by Professor West, at Providence. Several valuable papers on the subject are contained in the first volume of the Transactions of the American Philosophical Society. Honourable mention of all the American observations is made by Montucla. " Cette partie du monde," he remarks, " a accueilli l'astronomie avec un zèle digne de l'ancienne Angleterre." From La Lande's remarks, when expressing his vexation at the tardy transmission of accounts from this country of the total eclipse of the sun in 1806, we may have reason to apprehend, that the good opinion, expressed by Montucla, is, in some degree, impaired.

mean distance of the earth from the sun, 23,984 semi diameters of the earth.*

In 1769, Dr. W. inserted in one of the Boston newspapers some observations on the brilliant Comet, which first appeared in September of that year, the tail of which he informs us, was 45 degrees in length. In September 1770, he published in a similar way his remarks on another Comet, which appeared in June, and passed its perihelion in August of that year. This Comet, he observes, was remarkable on two accounts, for having no tail, and for its swiftness. It was dis-

* From the data in the text, and considering a mean semi diameter of the earth equal to 3956 miles six tenths, the mean distance of the earth from the sun is 94,895,094 miles. This exceeds the computed distance given by Dr. W. in his second lecture on the transit, the sun's parallax being then estimated by him as 8″, 68.

The relative distances of the several planets are known by the application of Kepler's famous law of the constant ratio between their distances from the sun, and the periodic times of their revolutions. The relative mean distances of all the planets from the sun is expressed by the following numbers, that of the earth being reckoned as 10.

Mercury, 4. Venus, 7. Earth, 10. Mars, 15. *Vesta*,* 24. *Juno*,* 27. *Ceres*,* 27½. *Pallas*,* 28. Jupiter, 52. Saturn, 95. Herschell, 191.

These four small planets (with this mark *) denominated *Asteroids*, by Herschell, have all been discovered since the commencement of the present century, in the following order; *Ceres*, in 1801, by Piazzi, of Palermo. *Pallas*, in 1802, by Olbers, of Bremen. *Juno*, in 1804, by Harding, of Lilienthal. *Vesta*, in 1807, by Olbers.

covered here, he informs us, on the 26th June, in the evening, in opposition to the sun, traversed the northern hemisphere with uncommon rapidity, and within eight days disappeared in the morning twilight, describing in one day, 1st July, more than 40 degrees. This excessive swiftness he ascribes to its near approach to the earth on that day within one fiftieth part of the earth's distance from the sun. Though it continued so short a time, Doctor Winthrop made such observations as enabled him to calculate its elements. This Comet was remarkable for the small inclination of its orbit to the ecliptic, being only 1° 42′ according to Professor Winthrop; 1° 34′ according to Pingré. The revolution of this Comet in its orbit appears, by the laborious calculations of Lexell and Burckhardt, to be only five years and a half. Its non-appearance, since 1770, is attributed to a change in its orbit, by the action of the planet Jupiter.

The performances which have been mentioned, and the very able manner in which the laborious duties of his station were performed, during the long period of his professorship, gave a high reputation to Professor Winthrop, and to the College with which he was connected. All, who received the benefit of his instruction, unite in expressing their sense of his singular ability for communicating knowledge, his dignified and impressive manner, his happy talent of fixing and rewarding the attention of his pupils. His vigorous and comprehensive mind was not limited to mathematical and philosophical studies. "In the va-"riety and extent of his knowledge," says one of his biographers, "he has seldom been equalled. While he "wrote latin with purity and elegance, and studied the "scriptures with critical attention in their original "languages, he was also versed in several of the mo- "dern languages of Europe. He had deeply studied "the policies of different ages; he had read the prin- "cipal fathers; and he was thoroughly acquainted "with the controversy between Christians and de- "ists."*

In the ascription of these attainments, the writer is supported by the testimony of his cotemporaries, particularly of president Stiles and Dr. Chauncy—"I "suppose none will dispute, says Dr. Chauncy, his "being the greatest mathematician and philosopher "in this country; and was the world acquainted with "his other accomplishments, he would be ranked "among the chief for his learning, with reference to "the other sciences. He is in short a very critical "thinker and writer; knows a vast deal in every part "of literature, and is as well able to manage his know- "ledge in a way of strong reasoning as any man I "know. He went along with me in a particular "study for nearly two years. I had many written com- "munications from him, and he from me, not so much "by way of dispute, as by joining our forces in order to the investigation of some certain truths."†

In the political controversies which arose soon after the peace of 1763, Dr. Winthrop took a decided part in behalf of the colonies. "He had much influence".

* Allen's Biog. and Hist. Dict. † Hist. Coll. vol. x.

says Dr. Eliot, "from his knowledge and the weight "of his character. He was chosen one of his majesty's "council, when Mr. Hutchinson was in the chair of "government, who did not negative him; but in the "year 1774, a royal mandate was issued to nega- "tive three gentlemen who had been most active in "opposing the measures of the administration; these "were Mr. *Bowdoin*, Mr. *Dexter* and Mr. *Winthrop*."*

These respectable gentlemen were not intimidated, nor did they consider themselves degraded, by this royal frown. We learn from Professor Wigglesworth, the elevated sentiments with which it was received by Dr. Winthrop. Mr. Bowdoin was raised to the chair of government, after his country, whose rights he had so ably advocated, had gained its independence. He had then to experience the uncertain continuance of public favour; but he still enjoyed the precious consciousness of pure intention, and all that estimation, which the wise and virtuous hold most dear.

In popular impulse, as well as in cabinet devices, there is sometimes an obliquity, to which such men cannot be made to accommodate. A rectitude, which should command admiration, frequently renders them victims to political intolerance; denunciation and exclusion from office in such cases, can be no reproach to their characters, and are seldom permanently injurious to the cause which they espouse.

Virtus repulsæ nescia sordidæ
Intaminatis fulget honoribus.

* Biog. Dict.

When the royal control which had rejected Dr. Winthrop was at an end, he was re-chosen into the council. In this difficult and responsible station he remained during a period eminently critical and trying. He was also appointed Judge of Probate for the county of Middlesex; which office he held until his decease.

"The best part of Dr. Winthrop's character," says Dr. Eliot, "was, that he was a Christian philosopher. "He believed the truths of Christianity from study "and conviction, and was an ornament to his profes- "sion. To his numerous acquaintance he was a "friend, philosopher, and guide." "In frequent "and distressing sickness," says Dr. Wigglesworth, "no complaint ever came from his lips. He sup- "ported himself with a manly fortitude and a sober se- "renity, which christianity alone could inspire." He died May 3, 1779, aged 65.

The discourses delivered by President Langdon, Professor Wigglesworth, and the Rev. Dr. Howard, occasioned by the death of Dr. Winthrop, all express his emphatic testimony to the truth of the gospel, made ~~before~~ the day before ~~of~~ his departure.

"I view religion as a matter of very great impor- "tance. The wise men of antiquity set themselves "to work to prove the reality of a future state. They "catched at every thing which had the shadow of "probability. They gave a degree of plausibility "to the argument. They were sensible of the need "they stood in of such a doctrine. In opposition to "the wise men of antiquity, the wise men of modern "times have employed their abilities in undermining "every argument in favour of immortality, and in "weakening the only hope that can sustain us. But "the light thrown on this matter by the glorious gos- "pel, with me amounts to demonstration. The hope "that is set before us in the New Testament is the "only thing which will support a man in his dying "hour. If any man builds on any other foundation, "in my apprehension his foundation will fail."

In his writings also will be found decisive marks of a religious turn of mind, and of a settled disposition to direct philosophy to the noble objects, emphatically expressed by Bacon, "the glory of the Creator and the good of man's estate."

The following lines, published anonymously at the close of Professor Wigglesworth's Discourse, are understood to have been written by Andrew Oliver, Esq.

AN ELEGY

ON THE LATE PROFESSOR WINTHROP.

BY A GENTLEMAN, FORMERLY HIS PUPIL.

Ye Sons of HARVARD! who by *Winthrop* taught,
Can travel round each planetary sphere;
And, wing'd with his rapidity of thought,
Trace all the movements of the rolling year;
Drop on his urn the tribute of a tear.

Ye, whom the love of Geometry inspir'd,
To chase coy Science through each winding maze;
Whose breasts were with Newtonian ardor fir'd,
Catch'd by his sparks, and kindled at his blaze:
In grateful sighs, ejaculate his praise.

Ye philosophic souls! whose thoughts can trace
The wonders of the architect divine,
Through depths beneath—o'er nature's verdant face,
Where meteors play—where constellations shine;
Heave the deep groan—and mix your tears with mine.

Ye tenants of the happy seats above!
Welcome this late inhabitant of clay,
From hostile factions, to the realms of love,
Where he may bask in everlasting day.
Ye kindred spirits waft him in his way.

When in their sockets, suns shall blaze their last;
Their fuel wasted, and extinct their light:
And worlds, torn piecemeal by the final blast;
Subside in chaos and eternal night:
He still shall shine
In youth divine,
And soaring on cherubic wing,
Shall like an ardent Seraph blaze,
And in unceasing raptures, to his maker's praise,
Eternal Hallelujahs sing.

BIOGRAPHICAL NOTICES

OF

ANDREW OLIVER, ESQ.

ANDREW OLIVER, Esq. author of the Essay on *Comets*, was born in Boston, A.D. 1731. He was the eldest son of Andrew Oliver, Esq. Secretary of the Province, and afterward Lieutenant Governor. He was educated at Harvard College, and received his first degree in the year 1749. Having married a daughter of the Hon. Judge Lynde, he was induced to remove to Salem. He was a man of genius, and distinguished for his philosophical researches. His circumstances were such that a life of business was not necessary for his support; and he was able to indulge, without impediment, his prevailing love of literature and science. Besides the Essay on Comets, he wrote an elaborate paper on *Thunder Storms*, and another on *Water Spouts*, which were published in the second volume of the Transactions of the American Philosophical Society: Of that Society he was a member, and one of the original members of the American Academy of Arts and Sciences.

This gentleman was not only a proficient in Natural or Experimental Philosophy, but was well skilled in Geometry, and other branches of Mathematics. He was fond of music, and studied it theoretically, and occasionally indulged a taste for poetry; but excepting his Elegy on the death of Dr. Winthrop, we are possessed of none of his poetic performances, though several are said to have been published. He was also particularly attached to history, which was the principal solace of his leisure hours, when free from the pain of a chronic disease, with which he was afflicted for more than thirty years of his life. He occasionally amused himself, like the sagacious Dr. Wallis, and many other men of scrutinizing minds, with deciphering. In this he became such a proficient, that it has been observed, he never met with a cipher which eluded his research.

His studious habits, as well as his state of health, induced a life of much seclusion from general society: Yet there was no asperity or gloom in his composition. In his temper and disposition he was cheerful, affable, and benevolent; ever ready to listen to the voice of distress, and promptly to administer relief. He was a Judge of the Court of Common Pleas, in the county of Essex, before the revolution: and was appointed one of the Mandamus Counsellors in 1774. The office had been unsolicited on his part, and he was the first to resign it. He was a friend to free inquiry in religion and in politics, and a believer in the doctrines of Christianity. After a long and painful sickness, which he sustained with singular equanimity and resignation, he died at Salem, in 1799, aged 68.

Mr. Oliver's Essay on Comets was published in 1772. It has ever been considered a very ingenious and respectable performance by intelligent men in this country, and was well received abroad. It was translated into the French language at Paris. M. Bailly, the celebrated and unfortunate author of the History of Astronomy, makes respectful mention of Mr. Oliver's conjectures and reasonings. He notices a correspondence between his ideas of repulsion, and an opinion of Buffon's relative to the cause of the expansion of fire and light, and after giving an analysis of the contents of the *Essay*, concludes with this observation. "The whole of this work is extremely "ingenious—the system is highly probable; more "than this should perhaps be said of the application "of a repulsive force, and of electric phenomena, to "the appearances of the tails of Comets."*

Mr. De Luc, in the Journal De Physique, 1802, after combating a supposition of Louis Bertrand, that Comets are designed to produce periodic displacements of the ocean for the renewal of the terrestrial continents, suggests a scheme of their constitution and use, in a great degree conformable to Mr. Oliver's system, both in outline and in explanations.

* "Tout cet ouvrage est infiniment ingénieux ; le systême "est très-vraisemblable ; et peutetre l' application de la force "répulsive et des phénomènes électriques aux phénomènes de "la queue des cometes merite-t-elle un autre nom." And again, "Il semble quil n'y ait rien à répondre á l' application que "l'auteur fait des expériences de M. Franklin."

The physical constitution of these bodies, their destination and use, are among the arcana of nature. Every new appearance of a Comet revives discussion on their dubious phenomena, and suggests inquiries, of difficult solution. To all who may contemplate the subject, Mr. Oliver's Essay will be an acceptable aid; and if the great question attempted to be solved, should still be thought doubtful, the reader will find his attention rewarded by a valuable collection of facts, and an ingenious display of philosophical reasoning in their application.

ADDITIONS TO THE BIOGRAPHY OF DR. WINTHROP.

Dr. Winthrop was among the earliest members of the American Philosophical Society; and one of the Corporation of Harvard College, from 1765, until his death. He was twice married. His first wife died in 1753. The second survived him, and died, a widow, 1790. They were both amiable and accomplished women. He had five sons, all from the first marriage. Two of them are now living; the Hon. James Winthrop, and Hon. William Winthrop, both of Cambridge. The *Cogitata de Cometis* were inserted in the Transactions of the Royal Society, 1767, and not published separately A few copies only, were separately printed for the author's use.

ERRATA.

p. xiii, line 21, for *hujusque*, read *hucúsque*. p. xv, 6 lines from the top, in some copies, for 145, read 45. p. xv, in the note, line 1, for *date*, read *data*. p. xviii, line 4, from the bottom, for *is*, read *are*. p. xix, line 22, for *before the day of his departure*, read *the day before his departure* p. 168, line 15, for 90,505,932, read 95,505,932. p. 188, line 4, from bottom, for *spero*, read *assero*.

TWO

LECTURES ON COMETS,

READ IN THE CHAPEL OF HARVARD COLLEGE, IN CAMBRIDGE, NEW ENGLAND, IN APRIL 1759, ON OCCASION OF THE COMET WHICH APPEARED IN THAT MONTH.

WITH AN APPENDIX, CONCERNING THE REVOLUTIONS OF THAT COMET AND SOME OTHERS.

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PUBLISHED BY THE GENERAL DESIRE OF THE HEARERS.

1759.

ON COMETS.

LECTURE I.

The appearance of the Comet, with which our heaven is now adorned, has induced me to quit at present the subject we were considering in the course of these lectures, in order to lay before you some account of this extraordinary sort of bodies, which in all ages have commanded the attention of mankind. In treating which subject, I shall first briefly examine the principal hypotheses that have prevailed concerning Comets, and then explain more largely the true theory of them, according to the latest discoveries.

Every one knows that there are two sorts of stars commonly to be seen in the heavens; some, moveable; others, immoveable. The immoveable ones, generally called *fixed* stars, have this title on account of their retaining invariably the same distances from, and positions towards each other. The moveable ones are called *Planets*, from the greek word πλανητης, which signifies a *wandering* star; because they are perpetually changing their places with regard to the fixed stars, and to one another. Both of them shine, when the air is clear, with a brisk and vivid light.

The *Comets* are a third sort of stars; moveable like the planets, but greatly differing in several particulars from them, as well as from the fixed stars. The bodies of them usually appear different from all the other stars; being of a dull and dusky light, like that of a star shining through a thin cloud. They are incompassed with an haziness, called their *atmosphere*, which generally appears much larger than the body, or, as it is otherwise called, the *nucleus* or *head* of the Comet. But what most remarkably distinguishes them from the rest of the stars is their *tail*, which is a train of pale light, extended from their atmosphere, sometimes to very great lengths. From an imagined resemblance of this to *hair*, a star of this sort was termed in greek κομητης, that is, an *hairy* star; which was the original of our word *Comet*. The matter of which this tail consists is so extremely rare, that the smallest stars appear through it without any diminution of their lustre. When the tail is of a considerable length, it has a sensible curvature, convex on that side to which the Comet is moving; but if it be short, this curvature is scarcely perceived. It is generally broader towards the end than near the head of the Comet, and of a fainter light; and its direction is opposite to the sun;—not exactly so indeed, but deviating a little that way from which the Comet has moved. Sometimes it is bifurcated, like two branches proceeding from one stem. It sometimes appears to go before the head of the Comet, and sometimes to follow it; and sometimes to surround it on all sides. The apparent courses of Comets also differ very much from the planetary ones. The planets never depart far from the ecliptic; whereas Comets range through all parts of the heavens. And as they make their first appearance indifferently in any constellation, though most commonly within 90° of the sun, or in some part of that hemisphere which has the sun in the middle of it; so they move indifferently any way, either from south to north, or from north to south; and sometimes are seen to run off even to the very poles. In one particular indeed, their motions agree with those of the planets. For as the planets are sometimes seen to proceed with a *direct* motion, or from west to east, and then, in other aspects with the sun, to be *retrograde*, or go backwards from east to west; so have several Comets, whose motion was at first direct, become afterwards retrograde; and others have altered their course from retrograde to direct. Comets are not always to be seen, as the planets are; but only occasionally, and after uncertain intervals of time. Sometimes several have been discovered within the compass of a few years; but for the most part, their appearances have not been so frequent. They are seen but a little while, only for a few weeks, or months at most; and though when they first shew themselves, some of them are bright and large, equal in apparent diameter to Jupiter and Venus, and almost the * moon itself; yet they are commonly observed to diminish in

* As the Comet of 1652. Hevelii Cometogr. Lib. vi. p. 326.

magnitude, in brightness, and in the length of their tail, until they become quite invisible. Such are the general phœnomena of Comets; and these the tests, by which every hypothesis concerning them is to be tried.

A variety of opinions hath been entertained, as to the nature and place of these bodies. Some have looked upon them to be worlds on fire;* and some, nothing more than lucid meteors: and while many have confined them within the narrow limits of our atmosphere, others have raised them up to the fixed stars. So widely do men differ, when, instead of searching into the nature of things, they indulge their own imaginations.

It was an ancient doctrine of some *Pythagorean* philosophers,‡ that the Comets are a peculiar kind of wandering stars; that they are to be reckoned among the permanent bodies of the universe; that they move in their proper orbits, completing their courses in stated times: but that they are visible only in a small part of their orbits, and return not again till after a long period of years; being too remote, during the greatest part of their revolution, to be discerned by us. But the *Peripatetic* scheme afterward prevailing, the philosophers of that sect, who held that the heavens are absolutely immutable and incapable of generations and corruptions, regarded the Comets, not as stand-

* Which seems to be the idea conveyed by our vulgar term *blazing stars*.

† Gregorii Astron. Lib. v. Sect. i.

ing works of nature, but as new productions which quickly perish; and maintained them to be only a kind of meteors formed out of the exhalations of our atmosphere, and much below the moon; being apprehensive that, if they were placed higher, their appearing and disappearing so uncertainly would divest the heavenly region of that privilege of immutability which they had assigned it. In this they were confirmed by another notion they had taken up, that the planets were carried round in their courses by solid crystal orbs; through which, to be sure, the Comets could not penetrate. Thus does one error lead to another. And by the way, the prevalance of this opinion has had an ill effect, and has been the true reason why this most curious part of astronomy, which relates to Comets, lay uncultivated for so many ages; the philosophers, who had imbibed such notions, thinking it to no purpose to describe with accuracy the irregular motions of such vanishing vapors. Had the ancients observed the paths of Comets among the fixed stars with the same care as they did those of the planets, the astronomy of Comets had, in all probability, by this time been brought to almost the same perfection with that of the planets. But as the opinion, that the Comets were meteors and below the moon, obtained for many ages almost universally, and was the only one publicly taught till the time of TYCHO BRAHE, an eminent astronomer of the sixteenth century, it has hence come to pass, that we have nothing certain transmitted to us, of the motion of any Comet, till within these last 200 years;

those which appeared before, having not been described by astronomers, but only mentioned by historians as prodigies, or omens of dreadful calamities. But Tycho, having carefully observed a remarkable Comet, found by repeated trials, that it was not subject to a diurnal parallax; for it appeared at the same time in the same place among the fixed stars, to two observers at the distance of several hundred miles from each other. This observation at once overthrew the doctrine of the schools, and placed the Comet far above the moon. The astronomers, who came after Tycho, having diligently watched the Comets which appeared in their days, have found that the diurnal parallax of all of them is either wholly imperceptible, or extremely small;—a demonstration, that Comets cannot be ærial meteors, but ought to be ranked amongst the heavenly bodies. Indeed, their partaking of the apparent diurnal motion of the heavens might have taught those philosophers better, and was a sufficient indication that Comets are not appendages of the earth.

As the want or smallness of a diurnal parallax has raised Comets above the moon, so from their being subject to an annual parallax it is certain that they are not among the fixed stars, but descend into the region of the planets. Though they are at too great a distance to have their apparent place altered by being viewed from different parts of the earth, yet they come near enough to have it altered by being viewed from different parts of our annual orbit. Accordingly, their apparent motion is sensibly affected by the annual motion of the earth, in the same manner as that of the planets is. The real motion of all the planets round the sun is constantly direct, or from west to east; and not very unequal in the several parts of their orbits; and would appear to be so, if viewed from the sun, which is fixed in the centre of their orbits; but their apparent motion, as viewed from the earth, which moves the same way as they do, is very various. Sometimes they are seen to go swifter, sometimes slower, with a direct motion; then to be retrograde, going the contrary way, or from east to west; and between these opposite motions, they appear for a little while stationary, or without any motion at all. These appearances depend on the motion of the earth, as that happens to conspire with, or be contrary to, and to be swifter or slower than, the real motion of the planets. And for the same reason must the apparent motion of Comets be changed, if they move within the planetary orbs. Those, whose real motion is direct, will appear stationary and retrograde, or at least much slower, in nearly the same aspects with the sun, as the planets appear so; but those, whose real motion is retrograde (for such is the motion of some Comets) will, in the same aspects, appear stationary and direct. And conversely, since this is the case in fact;* since the visible motion of Comets is altered, as the earth's annual motion would require on the supposition of their coming into the region of the planets, it

* See before, p. 3.

follows, that they do come into the region of the planets. Thus, by the way, the Comets supply us with a new proof, that the earth revolves round the sun; for without supposing this revolution, their motions cannot be reduced to any sort of regularity. So far indeed are Comets from being among the fixed stars, that it appears from their annual parallax, that they are seldom seen till they come within the orb of Jupiter,* and that they frequently descend below the orbs of Mars and the inferior planets.

Some astronomers, who had rightly placed Comets in the region of the planets, have been mistaken in their thoughts on the constitution of these bodies. It has been supposed, that Comets were formed by the coalition of some subtle exhalations from the planets; and that they were, with regard to the sun, of the same nature as what are called *shooting stars*, with regard to the earth. But this opinion is overthrown by what Sir Isaac Newton has observed† of the remarkable Comet which appeared in the year 1680. The earth is above 160 times farther from the sun, than that Comet was in its perihelion. Now the heat of the sun, being as the density of the rays, is in every place reciprocally as the square of the distance of that place from the sun; and therefore, the heat of the sun at the Comet in its perihelion was above 26000 times greater than it is at the earth. But the heat of boiling water is about three times as great as that which dry earth contracts from the

* Newtoni Principia, p. 430. † Princip. p. 508.

summer sun; and so the heat at the Comet was about 9000 times greater than that of boiling water. And the heat of red-hot iron Sir Isaac conjectures to be about three or four times greater than that of boiling water; wherefore the heat, which dry earth on the Comet in its perihelion might contract from the rays of the sun, was about 2000 times greater than that of red-hot iron. But by so intense an heat as this, all volatile matter must presently have been consumed and dissipated; and the Comet, which could endure this most violent heat, certainly did not consist of vapors or exhalations of any kind.

Different conjectures have been proposed to account for that peculiar phœnomenon of Comets, their *tails*. That these depend in some manner on the sun, is plain from their perpetually pointing to the part opposite to the sun; as hath been observed of all the Comets within these last 200 years. This, in the general, the later astronomers have agreed in; but have differed in explaining the particular manner in which the sun produces such an appearance. Some have thought the tails of Comets to be nothing but the rays of the sun transmitted through the body or head of the Comet, which for this purpose they are obliged to suppose transparent; and so yielding the appearance of a sun-beam *behind* the Comet, that is, on the side opposite to the sun. And others have added, that the rays are refracted in passing through the head, as through a glass lens. This they illustrate by the example of the sun's shining through a small hole into a darkened room, in which case a stream of light is seen extended from the hole. But this hypothesis will by no means account for the phænomenon in question. It might be urged against it, that the transparence of the Comet is an arbitrary supposition; and that for the most part, the figure does not answer; such a stream of light in a darkened room being always perfectly straight, whereas the tails of Comets are often curved: neither does the direction answer; such a stream of light being always exactly opposite to the sun, whereas the tails of Comets usually deflect a little from the precise point of opposition. But not to insist upon these arguments, it should be considered, that a sun-beam in a darkened room is perceived, only so far as the light is reflected from the particles of dust and smoke, which are always floating in the air. For the rays of light in the beam are not discerned by an eye placed on the side of it, any otherwise than by being reflected to the eye from some substance in the place where the beam appears. And hence it is, that when the air is full of thick smoke and dust, such a sun-beam appears brighter; for there being then a greater number of reflecting particles, a greater number of rays are reflected, and strike the eye more strongly. When the air is more clear and free from motes, the sun-beam appears fainter, and is not so easily perceived; and if there were no reflecting matter there at all, it could not at all be perceived. Since therefore vision is caused only by those rays which fall on the eye, it is necessary to suppose some reflecting matter where the tail appears; and this matter must be grosser and denser in that place than in the other ætherial regions; otherwise, the whole heaven, being equally illuminated by the sun, would shine as much as the tail of the Comet, and appear throughout of an uniform brightness. The tail therefore does not proceed from the rays of the sun transmitted through the head of the Comet.

A late author has attempted to mend this hypothesis, by supposing that the rays of the sun are refracted in passing through the atmosphere of the Comet, and so made to converge on the part opposite to the sun; and the light being by this means condensed, illuminates that part of the atmosphere, enough to render it visible to us; and that this illuminated part is what is called the Comet's *tail.* But besides that this opinion is liable to almost the same difficulties as the foregoing, it supposes the atmosphere of a Comet to be extended all round the body, though invisibly, to the same distance as the tail is, which in some cases has been many millions of miles;—a supposition, which, without some further proof, will not easily gain belief.

Others, who saw the insufficiency of the foregoing hypothesis of the transmission of light, have advanced another, still more improbable, and endeavoured to account for the tails of Comets by the refraction of light in its passage from the head of the Comet to the earth. They have supposed that as the round image of the sun, by being refracted in passing through a glass prism, is thrown into an oblong form; so the light proceeding from the round head of the Comet may, in passing through the ætherial regions, be refracted in such a manner as to appear long, and produce this phænomenon of the tail. To this opinion it is an obvious objection, that the rays of the fixed stars and planets, since they pass through the same medium as those which come from Comets, are liable to the same refraction, and ought therefore to exhibit the same appearance; and some of these should have larger and brighter tails than most Comets, since their light is much stronger. But even those stars and planets, whose light is strongest and most copious, have no tails; nor can any be discovered belonging to them by the best telescopes, which will increase their light above an hundred times; while some Comets, whose light was but weak and dull, have had very large and bright tails. Besides, the tails of Comets are never variegated with colours, as the oblong image produced by the prism is; which variety of colours is a necessary result of that unequal refrangibility of the rays, by which the prismatic image, instead of being round, is made oblong. Farther: If the tail arose from the refraction of light in its passage through the heavens; whenever the light passes through the same part of the heavens; it ought to be refracted the same way. But this is contrary to observation. For two Comets have been seen in the same place of the heavens, when the earth was likewise in the same part of its orbit; yet their tails have not been turned the same way, but have contained a large angle between them.* This difference in their direction could not be the effect of a refraction in the heavens, which in such circumstances must have been the same. These causes therefore being rejected, the phenomena of the tails must be derived from some matter in them, which reflects light.

The ascent of the tails towards the parts opposite to the sun, some authors of note have ascribed to the action of the sun's rays, driving the matter of the tail before them. And considering the extreme rarity of the vapour which composes the tail, and the surprising velocity of the rays of light, perhaps it may not be altogether impossible for the matter of the tail to yield in some measure to the impulse of the rays, and be driven before them that way towards which their motion is directed; that is, to the parts opposite to the sun. But if such a cause should be allowed to have some small share in producing the phænomenon, yet this can hardly be deemed an adequate solution; nor should much stress be laid upon it, as we know of no parallel instance in nature to support it.

As to the line in which Comets move, some of the most considerable astronomers of the last century supposed it to be a strait line, or nearly so. KEPLER, from his own observations of two Comets, concluded

* A remarkable instance of this may be seen in Newtoni Principia, p. 510, 511.

that they moved freely any way between the orbits of the planets, with a motion not very different from a rectilinear one. HEVELIUS, who carefully observed several Comets, embraced the same hypothesis; but was sensible that his calculations founded upon it did not perfectly agree with the heavens, and perceived that the path of a Comet was in a line incurvated towards the sun. But what this curve is, these astronomers, like all who went before them, were unable to determine.

We have now set aside some of the false opinions concerning Comets, which have been most regarded. It has been shewed that they are neither below the moon, nor among the fixed stars; that they consist not of any kind of exhalations;—that their tails are not produced by the transmission of light through their bodies; nor by any refraction of light, caused either by their atmospheres or by the celestial matter through which it passes;—that the tails are not turned opposite to the sun by the impulse of his rays; and lastly, that the motion of Comets is not in strait lines. Some better account of these things is therefore to be sought for.

Indeed, the opinions concerning Comets, which formerly passed current with many, were suspected by others. Thus SENECA the philosopher, dissatisfied with the doctrine of his time relating to them, and unable to substitute a better, foretold, that "in "future ages, some man would demonstrate in what "parts of the heavens the Comets wander, why they "depart so far from the other wandering stars, and "what sort of bodies they are."* The prediction has been fulfilled in the present age; and this man was Sir ISAAC NEWTON. After many centuries elapsed, with little insight gained into the true constitution of these bodies, and none at all into their real motions, this great genius arose, and with a strength of mind peculiar to himself (I had almost said, more than human)

> "Pursu'd the Comets where they farthest run,
> "And brought them back obsequious, to the sun,"

as POPE has happily expressed it. Formed to penetrate into the most abstruse recesses of nature, he traced these unknown travellers through every step of their long journey, delineated the particular tour they make, and shewed by what secret influence they are determined to revisit our planetary regions, after an absence of scores, or rather centuries of years. The explication of these particulars you may expect in the next discourse.

* Seneca Natural. Quæst. Lib. vii. Cap. xxvi.

Read, 11th of April, 1759.

LECTURE II.

In the last discourse we examined such of those false hypotheses concerning Comets, as had been most regarded in the world. I then took no notice of some others which have been advanced upon this head, because, as they carried less shew of probability, they have had fewer and less considerable advocates, and in consequence have fallen into neglect. And for the same reason, I shall not spend any of the time allotted for the present exercise in the confutation of such hypotheses, but enter immediately upon the explanation of the true theory of Comets, for which the world is indebted to the unparalleled invention of Sir Isaac Newton. And here we shall begin with shewing what their real course in the heavens is, as that will throw light upon some other parts of their theory.

An essential part of Sir Isaac's doctrine is, that ancient *Pythagorean* one already mentioned,* viz. that Comets are a kind of wandering stars, which are moved in peculiar orbits of their own. This doctrine received hardly any improvement until his time, but he alone carried it to an height, which might rather

* In p. 4.

have been wished for than expected; and has left those who come after him little to do, but to apply his theory to the several Comets, as they shall appear. According to this excellent philosopher then, The Comets are a kind of planets, that is, firm, compact, durable bodies; revolving round the sun in conic sections, and, by right lines drawn to the sun, describing areas proportional to the times. That they are not formed of exhalations or vapors, but are firm, durable bodies, was shewed the last time; as also, that the astronomers before NEWTON, who supposed their trajectories to be nearly rectilinear, perceived they were not accurately so, but were rather bent in towards the sun; though what the particular line of this motion was, they were not able to determine. But Sir ISAAC NEWTON has demonstrated from his principle of *gravity*, that it must be some one of the conic sections. For, having discovered that all the globes in our system mutually gravitate towards each other with forces reciprocally proportional to the squares of their distances; and that by this gravitation of the primary planets to the sun, they are restrained from going on in right lines, and are compelled to move in curvilinear orbits; he next demonstrated,* that whenever a body is made to revolve round another, by such a centripetal force as this,—by a force which at all distances from the central body is reciprocally as the squares of the distances, the revolving body must necessarily describe some conic section, in one focus

* Princip. Lib. i. Prop. xvii.

of which the central body will be placed. And the species of the orbit will depend on these two circumstances;—on the proportion which the velocity or projectile force of the revolving body bears to the force of its gravitation towards the central one; and on the angle contained between the directions of these two forces. The planets therefore, whose motions are governed by such a gravitating force, will move in some conic section. Accordingly, what KEPLER discovered is now established by the general consent of astronomers, that the orbits of all the primary planets are one sort of conic sections, viz. ellipses, in one focus of which the sun resides. The law is general, and extends to the secondary planets also; and the moon moves in an elliptic orbit which has the earth in one focus. And each of these planets, primary and secondary, by straight lines drawn to the central body, describes areas proportional to the times; and so moves swifter, as it comes nearer the centre: which law of their motion Sir ISAAC NEWTON has demonstrated to take place in all bodies revolving by any kind of centripetal force whatsoever.

These points being settled, and Sir ISAAC, finding, as has been mentioned,* that the Comets come within the planetary regions, and consequently within the reach of gravitation to the sun, concludes, by force of the forementioned demonstration, that they, as well as the planets, must move in some conic section about the sun. But there is no necessity that their

* See above p. 7.

orbits should be of the same species as those of the planets. The elliptic orbits of the planets are all different, and the orbits of the Comets may be different from any of them. The conic sections are three, viz. the hyperbola, parabola, and ellipsis; to which may be added, the circle. The two former of these are extended infinitely; the latter return into themselves. If the velocity of a Comet, at any distance from the sun, were in the same proportion to the velocity of a planet revolving in a circle at that distance, as the diagonal of a square is to its side, that is, nearly as 7 to 5, the Comet would move in a parabola;* and with a greater velocity, in an hyperbola: and in both these cases, having once passed by the sun, it would never return more; the velocity acquired in its descent being now great enough to throw it off to the fixed stars, so that its gravitation to the sun would never be able to bring it back. With a less velocity than this, a Comet would move in an ellipsis; or, with a certain adjustment of the circumstances, in a circle. If Comets be supposed to move in a parabola or hyperbola, their number must be vastly great, because the number of their appearances hath been so; and each appearance must have been of a different Comet, since, on this supposition, no Comet could be seen twice. Besides: we have no reason to think, that any of the bodies, which belong to our system, can belong also to any system among the fixed stars; which seem to be placed at

* Newt. Princip. Lib. i. Prop. xvi. Corol. 7.

such immense distances from us, with design to cut off all intercourse between them and us. Farther: it is certain that Comets do not revolve in circles, or in ellipses of a small eccentricity, as the planets do; for if they did, they would be seen constantly, as the planets are. But it is well known, that Comets are visible but a little while,* and continue invisible for a long time. It remains therefore, that they move in elliptic orbits of very great eccentricity; that is, whose length is very great in proportion to their breadth. But that small part of such an orbit, near the perihelion, which is all that can come under our observation, will almost coincide with a parabola; and may therefore, without any sensible error, be taken for one.

Here our author had occasion to exert his great abilities in solving a problem, the extreme difficulty of which rendered it worthy of his genius, and indeed insuperable by any other. From three select observations of the place of a Comet, supposed to move in a parabola, he has taught a method of delineating its trajectory geometrically;† and has given an example of this solution in determining the trajectory of that famous Comet which he himself observed in the year 1680. He made it certain that the Comet really moved in the trajectory he had delineated, by computing its places therein for the times of several ob-

* p. 3. † Newt. Princip. Lib. iii. Prop. xli.

servations; which agreed with its places as they were actually observed at those times.*

This excellent discovery has since been abundantly confirmed by the labours of the learned Dr. HALLEY, who, following the steps of Sir ISAAC NEWTON, has performed the same thing arithmetically, which that great man had done geometrically, and has expressed the orbits and motions of Comets by numbers. And having in this manner settled the orbits of all which had been well observed before the present century, to the number of 25, he found that their places computed in these orbits agreed as well with their observed places, as the computed places of the planets usually agree with their observed places. The like computations having been since made by other astronomers for the Comets which have been seen in this century, the theory is constantly found to answer the observations. In this manner have the orbits of about 40 Comets been settled.

All these calculations have been made on the supposition, that the visible part of a Comet's trajectory is so nearly parabolic, that it may safely be taken for such; though the whole orbit be really an ellipsis of very great eccentricity. Now the true species of an ellipsis so eccentric as the orbit of a Comet must be, cannot be determined with any exactness from such a small part of it as a Comet describes, while it conti-

* Jam patet horrificis quæ sit via flexa cometis;
Jam non miramur barbati phænomena astri. As Dr. *Halley* sings on this occasion.

nues visible: it can be determined no other way than from the periodical time of the Comet; and the periodical time will be known, by remarking the times when two Comets have described the same orbit. The only method, therefore, to perfect the astronomy of Comets is, to determine the trajectory of every one that appears, on the supposition of its being a parabola; for such a trajectory will always agree with the observations very nearly, as is evident from the great number of Comets whose trajectories have been thus settled. Then, when a Comet appears, if it be found to describe the same trajectory as some Comet has formerly done, that is, one whose nodes are in the same place; whose plane has the same inclination to the ecliptic; and which has its perihelion in the same place and at the same distance from the sun;—it may be concluded, that these are two appearances of one and the same Comet. And the conclusion will be the stronger, if it be found that several Comets, after equal intervals of time, have described the same trajectory; for then there will be no reason to doubt, that all these were one Comet, revolving in the same orbit. The intervals between these appearances will be the periodic time of the Comet; from whence its return may be predicted; and from whence also the longer axis of its elliptic orbit may be found, by the help of that famous rule which Kepler first discovered to obtain in fact, and which Sir Isaac Newton afterwards demonstrated must necessarily obtain in the revolutions of the planets; viz. that the squares of their periodic times are proportional to the cubes of their mean distances from the sun, or to the cubes of the longer axes of their orbits, which are double of those mean distances.

In this manner Dr. HALLEY first shewed, that the same Comet had, in all probability, made two or three appearances. For a Comet, which he himself observed in the year 1682, described an orbit that agreed very well with the orbit of the Comet observed by KEPLER in 1607. If these were one and the same, it revolves in the space of about 75 years; and the longer axis of its orbit will be found, by KEPLER's rule, to be about $17\frac{3}{4}$ times greater than that of the earth's orbit; and its distance from the sun in its aphelion about 35 times greater than the earth's mean distance from the sun. And that they were the same, is confirmed from hence, that in the year 1531 a Comet described an orbit, whose elements agree well with those of the other two; there being no considerable difference, excepting only in the periodical time; one interval being 75 years; the other, 76. But the inequality of the periods is not greater than what may be attributed to physical causes. For as the comet moved slowly in its aphelion, at which distance the sun's regulating power is but weak, its motion was liable to be much disturbed by the attraction of other Comets; by which means its periodic time might be considerably altered. The astronomers have found the motion of Saturn so much disturbed by Jupiter when near him, that some of his periods, observed accurately within a century past have been above 13 days longer than others. And by a calculation from the theory of gravity, some of Saturn's periods may be a month longer than others.* How much greater irregularities of this sort must our Comet be exposed to, which in its aphelion runs off from the sun almost four times as far as Saturn; where its gravitation to the sun is 16 times weaker; and whose velocity in its aphelion is not the tenth part of Saturn's velocity? It is not therefore to be wondered at, if its periodic time, and its orbit too, were somewhat changed.

Upon the supposition that it was the same Comet which appeared these three several times, the segacious Doctor predicted,* that "it would appear "again about the end of the year 1758, or the beginning of the following year." This prediction we have now the satisfaction to see verified; the present Comet agreeing hitherto so well with the former, as to leave little room for doubt that they are the same. We may therefore, upon sure grounds, expect that the rest of the Comets will return too; though we are not able as yet to prefix the years of their returns.† As it is not certain, that any other Comet has appeared twice, since Comets have been duly observed, we may conclude that all the other Comets have longer periods than this; and consequently run off to greater distances from the sun. From the curvature of the path of that which appeared in 1680,

* Halleii Tab. Astron. † See the Appendix.

Sir Isaac Newton collected that its period must be above 500 years; which will make its greatest distance from the sun to be above 126 times greater than the earth's. And this, by the way, shews the vast extent of the power of gravity; for it must extend to the utmost distance to which any Comets rise from the sun;—in order to turn them round their aphelia, and bring them back in their orbits, as it does the planets. To close the present article: a theory, which so accurately answers to the motions of all the Comets which have been accurately observed, even to some which have been very extraordinary,* and which accounts for them by the same laws as the motions of the planets are accounted for, cannot but be true.

Since Comets move in the planetary regions, we may argue that they shine by reflecting the sun's light; another circumstance, in which they resemble the planets. Accordingly, the brightness of their heads has been observed to increase as they have approached to the sun, and to decrease as they have departed from him; although they have been going farther from the earth in the former case, and in the latter, coming towards it. Which shews that their brightness depends, not on their nearness to the earth, as their apparent magnitude does; but on their nearness to the sun. And that Comets shine only by the light of the sun, is manifest from an observation of

* See the instances of the Comets in 1664 and 1680, in Newt. Princip. p. 505 and 522.

HEVELIUS, that some* have cast shadows behind them. Their shining only by the sun's light supplies us with a reason why they are most frequently seen near the sun, or in that hemisphere of the heavens, in the middle of which the sun is placed. For in their descent to the planetary regions, they are not sufficiently illuminated by the sun to discover themselves, till they come within the sphere of Jupiter.† Now the greater part of this sphere is on that side of the earth, which looks toward the sun, and therefore more Comets may be expected on that side than on the other.

You have now seen in what respects the Comets may be said to be a kind of planets. There is a conformity between them in these particulars: both of them are compact, permanent, opake bodies; both shine, not by native light, as meteors do, but by reflecting the sun's light; and both revolve in conic sections round the sun placed in one focus of their orbits, which, in all probability, are of the same kind, elliptic. But in other circumstances there is a difference. Their orbits, though elliptic, are vastly more eccentric or oblong than those of the planets; the former being almost parabolic; the latter, almost circular. There is a difference, as well in the situation as in the figure of their orbits. The planes of all the planetary orbits are almost coincident with the ecliptic; that which differs most, making with it an

* As that of 1665, whose shadow made a kind of fissure in the tail. Hevelii Cometogr. Lib. xii. p. 898. † p. 8.

angle of but 7°. But the orbits of Comets are inclined to the ecliptic in very different angles, some of them being almost perpendicular to it. The disposition of their orbits is indeed as various as possible in every respect; as any one will see, that looks into Dr. HALLEY's table of them. Again: the real motion of all the planets round the sun is constantly direct; whereas the real motion of many Comets* is retrograde, or contrary to that of the planets, as was intimated before.† This diversity in the *real* position of their planes, and in the *real* direction of their motions, occasions that great difference in their *apparent* courses, which we took notice of, under the head of their general phænomena.‡ Such a variety in the direction of these motions is, by the way, a full proof, that there are neither solid orbs in the heavens, as some of the ancients imagined; nor such whirlpools of fluid matter, as many of the moderns have introduced, in order to account for the planetary revolutions.

But Comets seem to differ from the planets in nothing more, than in that particular constitution of their bodies, or atmospheres, or both, which disposes them to have tails;—an appendage, not in the least degree belonging to any of the planets. You have already seen the insufficiency of some hypotheses which had been proposed to account for this appearance; and that the cause of it must be some ex-

* About one half of the known Comets are retrograde.

† p. 7. ‡ p. 3.

tremely rare vapor reflecting the sun's light. That the tail consists of some matter derived from the nucleus, may be argued from hence, that Comets have the greatest and brightest tails, quickly after they have passed by the sun; and those have the longest tails, which go nearest to him. By this it appears, that the heat, which the Comet acquires from the sun, tends to increase the tail. Thus, the Comet of 1680, when it was first discovered in its descent to the sun, had no tail; after some days, a small one arose, which increased in the approach to the sun; but soon after the Comet had passed its perihelion, which was not a sixth part of the sun's diameter distant from the sun, where it contracted a prodigious degree of heat,* it emitted a very splendid tail of a surprising magnitude, extending in length above 70°; which, considering its distance from the earth, fell little short of a hundred million miles. But this afterwards gradually diminished, until it totally disappeared. From hence it may be collected, that the tail is nothing but an extremely thin vapor, excited by heat from the nucleus of the Comet. Which is farther confirmed by a rule our great philosopher has given,† to determine at what time the vapor in the end of the tail began to ascend from the nucleus; by which rule he found, that almost all the vapor, which composed the tail of this Comet after it had passed its perihelion, arose at, and soon after the time of the perihelion, when it sustained the greatest heat.

* See above p. 8. † Newt. Princip. p. 513.

The tail of a Comet, being a vapor excited by the heat of the sun, must consist of matter of a texture different from what is in the planets. For some Comets have never come so near to the sun, as the earth always is; many have not been nearer to him than Venus or Murcury, and so have never been exposed to a greater heat than these planets continually are; yet have all these Comets sent forth considerable tails. Which shews that the matter of these tails was of such a peculiar texture as disposed it to be easily rarefied, without a great degree of heat. Since the atmospheres of Comets are vastly larger in proportion to their bodies, than those of the planets are, so far as we can judge of the other planets, by analogy, from our own; and since they abound much more with vapors, as is evident from their thick and turbid appearance; they seem to be a proper fund, to supply matter in sufficient plenty for the formation of the tails. For though some of these tails are vastly long, yet they are so thin, that an inconsiderable quantity of matter, duly rarefied, may suffice to produce them. We find, that a very little fuel will make smoke enough to fill a very large space.

The ascent of the tails in a direction opposite to the sun, our illustrious author thinks owing to the rarefaction of the matter of which they consist. For as in our atmosphere, where every thing gravitates to the earth, the smoke of any body mounts upward from the earth; and that either perpendicularly, if the body be at rest; or obliquely, if that be moved sideways:

so in the heavens, where all things gravitate to the sun, smoke and vapors ought to ascend from the sun; either right upward, if the fuming body were at rest; or obliquely, when that, by being in motion, leaves the places from which the superior parts of the vapor had ascended. "The air in a chimney, says Sir Isaac,* being rarefied by heat, becomes specifically lighter than the neighbouring air, and therefore necessarily rises in it, and carries up the smoke with it; and thus the vapor in the tail of a Comet being warmed, will warm the ætherial aura or solar atmosphere, wherein it is involved; which by this warmth being rarefied, and its specific gravity towards the sun diminished, it will ascend, and carry with it the matter which makes the tail;" and this matter, by its rarefaction, will continually expand on all sides, and make the upper end of the tail the broadest and thinnest. The ætherial aura must be supposed extremely rare and next to a vacuum, at the distance at which some Comets pass from the sun; yet, be it ever so rare, if that part of it, which is involved within the atmosphere and tail of a Comet, be made rarer by heat than the ambient parts are, it must rise in them, by the known laws of specific gravity.

From what has been said it appears, that the vapor, which makes the tail, has a compound motion;—a motion of ascent right upward from the sun, and a progressive motion, which it had in common with the nucleus. All the parts of it must therefore, by their

* Princip. p. 514.

gravity toward the sun, revolve round him in conic sections, for the same reason as the nucleus itself does; and, though detached from that, will accompany it in its progress, till by slow degrees they are dissipated. Here you may see the reason, why the tail is often a little incurvated, and sometimes bifurcated; and why it is not turned exactly to the point opposite to the sun. To keep the tail straight, and exactly turned from the sun, all the parts of it should describe greater arcs in the same time, and therefore move with greater velocities than the nucleus;—greater, in the same proportion as they are more distant from the sun. But the progressive motion, which they receive from the nucleus, can never give them a greater velocity than that has. Therefore the upper parts will be left a little behind, or on that side from which the Comet is moving; and the tail will be bent, with its convexity on that side toward which the Comet is moving. Farther: As the orbit of a Comet is very curve near the perihelion, those vapours, which make a tail before the perihelion, rise in a different direction from those after the perihelion. The consequence of this may be a forked tail; being, as it were, two tails, joined together near the nucleus, and divaricating toward their upper ends.

The tail, being always nearly opposite to the sun, will follow the head of the Comet, while that is descending to its perihelion; and will precede it, in its ascent. And if the Comet be near a straight line passing through the sun and the earth, and so be near its conjunction or opposition with the sun; the upper end of the tail being broadest, will appear to surround the head of the Comet on all sides, like hair.

Thus have we endeavoured to explain the general phænomena of Comets, enumerated in the beginning of the foregoing discourse. Concerning their uses and effects, two or three things are now to be said.

It is not to be doubted, that the allwise Author of nature designed so remarkable a sort of bodies for important purposes, both *natural* and *moral*, in His creation. The *moral* purposes seem not very difficult to be found. Such grand and unusual appearances tend to rouse mankind, who are apt to *fall asleep*, while *all things continue as they were* ;——to awaken their attention, and to direct it to the supreme Governor of the universe; whom they would be in danger of totally forgetting, were nature always to glide along with an uniform tenor. These *exotic* stars serve to raise in our minds most sublime conceptions of God, and particularly display his exquisite skill. The motions of many Comets being contrary to those of the planets, shew that neither of them proceed from necessity or fate, but from choice and design. The same thing is to be seen in the figure and situation of their orbits; which indeed have not the appearance of regularity, as those of the planets, and yet are the result of admirable contrivance By means of their great eccentricity, they run so swiftly through the planetary regions, as to have but very little time to disturb their own motions, or those of the planets. And this end is still more effectually answered in those Comets whose motion is retrograde, or contrary to that of the planets. In this case, the *relative* velocity wherewith the Comet and planet run by each other is the *sum;* but when Comets move the same way as the planets, it is the *difference*, of their real velocities.* By this great eccentricity likewise, as well as by the very different situation of their planes, they are at vast distances from each other in their aphelia; where their motions are so slow, and their gravitation to the sun so weak, that their mutual gravitation might produce irregularities, and perhaps throw the system into confusion; which this precaution has guarded against.

But without enlarging on these things, I must hasten to speak a little of the *natural* purposes, to which Comets may be subservient. To assign all these in particular, may perhaps never be in the power of mortals; to be sure, it is not to be expected at present, while our knowledge of the cometic system is but in its dawn. It does not seem very likely, that they

* The velocity of a Comet is to that of a planet, at the same distance from the sun, nearly as 7 to 5. Therefore the *relative* velocity of retrograde Comets is to that of direct ones as 7+5 to 7—5, that is, as 12 to 2. So that a retrograde Comet in its transit by a planet will continue within a given distance from it, but one sixth part of the time that it would, if it were direct. This would be strictly so, in case a Comet and planet should pass by each other in parallel directions. But the greater the deviation from parallelism is, so much the less difference will be made, in the time of their continuing near one another, by a Comet's being retrograde or direct.

should be intended, as the planets, to afford an habitation for animals. The very great excentricity of their orbits exposes them to such mighty changes of light and darkness, of heat and cold, as seem to imply that they are designed for purposes very different from the planets. If the Comet of 1680 revolves in 575 years, as some have supposed (and its period cannot be much shorter than this;* though it may be much longer) its greatest distance from the sun must be above 23,000 times greater than its least distance; and the light and heat of the sun being every where reciprocally as the squares of the distances, the Comet's greatest light and heat is above five hundred million times greater than its least. Extremes like these must, one would think, destroy all vegetables and animals, in the least degree resembling those we are acquainted with. And yet, such is the inexhaustible variety of the works of God, that it is more than possible, that there may be vegetables and animals, to which such extremes may be as necessary as those, to which our globe is subject, are to ours. However, it seems most probable, that the Comets are designed to be some way or other serviceable to the planetary worlds. Those who see with unphilosophic eyes are, I suppose, generally alarmed at the sight of a Comet; and indeed the bulk of mankind seem disposed, by a sort of natural superstition, to turn every unusual phænomenon into a presage of

* See above, p. 25.

some dire event. Of the truth of this observation, so far as it relates to Comets, the histories of them afford an incontestable proof. But these objects of terror may be productive of great advantages. It is the judgment of Sir ISAAC NEWTON,* that the tails of Comets may be intended to recruit the perpetual waste of fluids in the planets by vegetation and putrefaction. The tails sometimes reach to an immense distance;† and the rarefied vapor, dilating itself toward their upper end, must gradually be diffused throughout the heavens, and by its gravity be drawn into the atmospheres of the planets, and mingle with them. He farther suspects, that the most subtle and spirituous part of our air, which is most requisite to maintain life, may come principally from the Comets. Another end of them may be, to supply the perpetual consumption of the sun.‡ The Comet of 1680 descended so near to the sun,† that it probably entered, and that with an excessive velocity, into the denser part of his atmosphere, where meeting with a sensible resistance, it might be a little retarded; and if so, in its next revolution it will go nearer the sun, and be more retarded; and being thus retarded in every revolution, it must at length fall upon the sun, and may serve for new fuel to feed his flame. It may be more retarded by the attraction of other Comets in its aphelion, where its motion is very slow; and by that means may the sooner fall into the sun. Such may probably be some of the

* Princip. p. 515. † See above, p. 28.
‡ Princip. p. 525.

uses of Comets; and as our knowledge of their number, their periods, and the figure and situation of their orbits advances, more may be discovered.

On the other side, it ought not to be concealed, that they seem fitted to be the ministers of divine justice as well as goodness, and capable of producing very great and destructive changes in the planetary worlds; some of them having their nodes situated not far from the orbits of the planets. Were a Comet to pass very near a planet, it would increase the tides in the ocean (if the other planets have oceans as well as our earth) and might swell them so as to drown the lower countries, if not the mountains; and should the planet at the same time pass through the tail of the Comet, the vapours of that, supposing them to be aqueous, might, by turning into rain, greatly increase the inundation. By such a near approach of a Comet to the earth, has the ingenious and learned Mr. Whiston endeavoured to account for the universal deluge spoken of in the holy scriptures. And if he has not satisfactorily accounted for every particular upon this hypothesis, at least he has produced much more evidence of various kinds than could have been expected in a matter of such early antiquity, to prove that, in fact, a Comet came very near and passed by the earth, on the day the deluge began; and if so, it could not but have a very great influence in bringing on that most astonishing catastrophe. Indeed, according to the laws of nature, particularly those of gravity, it is not possible but that the near approach of a Comet to a planet, either in its descent to the sun or ascent from him, should draw after it a train of dangerous, if not fatal consequences. Several of these might easily be mentioned; and many others there may be, of which we have not at present the least suspicion.

But instead of entering here into a detail, which would probably answer no valuable end, I choose rather to turn your thoughts to that consummate Wisdom, which presides over this vast machine of nature, and has so regulated the several movements in it, as to obviate the damage that might arise from this quarter. None but an eye able to pierce into the remotest futurity, and to foresee, throughout all ages, all the situations which this numerous class of bodies would have towards the planets, in consequence of the laws of their respective motions, could have given so just an arrangement to their several orbits, and assigned them their places at first on their orbits with such perfect accuracy, that their motions have ever since continued without interfering, and no disasters of this sort have taken place; unless we except the case of the deluge. For though so many Comets have traversed this planetary system, and some of their orbits run near to those of the planets; yet the planets have never been in the way,* but always at a distance from

* The Comet of 1618 came to its descending node, the 19th of *September*. Dr. HALLEY observes, that if it had come to it about the middle of *March* [I think he should have said *May*] it would have passed within one twentieth of the sun's distance from the earth. And so would the Comet of 1686,

the nearest point, when the Comets have passed by it. The foresight of that great Being, which has hitherto prevented such disorders, will continue to prevent them, so long as He sees it fit the present frame of nature should subsist. Longer than that, it is not fit that it should subsist.

It may not be unseasonable to remark, for a conclusion, that as, on the one hand, it argues a temerity unworthy a philosophic mind, to explode every apprehension of danger from Comets, as if it were impossible that any damage could ever be occasioned by any of them; because some idle and superstitious fancies have in times of ignorance prevailed concerning them: So on the other, to be thrown into a panic, whenever a Comet appears, on account of the ill effects which some few of these bodies might possibly produce, if they were not under a proper direction, betrays a weakness equally unbecoming a reasonable being. The wisest course is, to aim at such a rectitude of intention and firmness of resolution, that, as HORACE says,

> Si fractus illabatur orbis,
> Impavidum ferient ruinæ.

Read, 18th of April, 1759.

had it arrived at its ascending node a little sooner. But no Comet has threatened the earth with a nearer approach than that of 1680; which, had it come down to the sun a month later, would have passed as near the earth as the moon is.

APPENDIX.

CONCERNING THE REVOLUTIONS OF THE PRESENT COMET, AND OF SOME OTHERS.

THIS year, 1759, has done great honour to astronomy. It has added a new confirmation to Sir ISAAC NEWTON's theory of Comets, which was indeed very well established before; and it has verified the first prediction that ever was made of the appearance of a Comet;—the first, I mean, that ever was made upon astronomical principles: For astrological or enthusiastical predictions of these or any other unusual phænomena deserve no regard, but are to be treated as the dreams of visionaries. And yet, trifling and contemptible as they are, such have been made both in former and later times.* This first astronomical prediction was made by Dr. HALLEY, in pursuance of the theory now mentioned; and the grounds, upon which he went in making it, have been laid open in the foregoing papers, p. 23. They were in brief: That the Comets, which appeared in the years 1531, 1607 and 1682 described trajectories in the heavens, the observed part of which was sensibly parabolic; and upon computation, their trajectories were found

* Halley's Synops. Astron. Comet.

to be nearly the same. The inference from which, according to the principles of this theory, is, that these were one and the same Comet, revolving in a very long elliptic orbit, in about 75 or 76 years. From hence the Dr. predicted, that "it would return "in the year 1758;" as he first published in 1705.* Having afterward looked over the catalogues of more ancient Comets, and discovered that three others had preceded the aforesaid three, in like intervals of time, viz. in the years 1305, 1380 and 1456, he was more confirmed in his opinion that they were the same Comet. But having remarked the inequality of its periods, that some were under 75 years, and others above 76, and considered the effect which the action of Jupiter upon the Comet, by the force of gravity, might probably have had, about the time of its last appearance in 1682, he concluded, that "it would not "return till after the longer period of above 76 years, "about the end of the year 1758, or the beginning of "the next."† With what sagacity and accuracy of judgment this conclusion was drawn, the event has sufficiently declared. At the same time he expressed his confidence, that "if it should return again at the "time he had foretold, impartial posterity would not "refuse to acknowledge that this was first discovered "by an *Englishman*." It is to be hoped, the present age will not forfeit the character of impartiality; but that all the world will now unite in doing justice to such distinguishing merit.

* Phil. Trans. No. 297. † Synops. Astron. Comet.

As this Comet is on some accounts more remarkable than the rest, I persuade myself a short *history* of it will not be unacceptable to the curious. I shall therefore throw together the principal things that I have met with concerning it.

Its first appearance, that may be depended on, is that in 1305. As to which, all we find is, that it was seen about Easter, that is, in April, as it was this present year; and that it was,* according to the language of those days, "of a horrible bigness:" Though it is likely it did not appear bigger at that time, than it did on the 29th of April last. For it could hardly ever have been seen much nearer to the earth, than it was this last time. It is to little purpose to look for any appearances of it prior to this. For though I find in HEVELIUS's and LUBIENIETSKI's Histories of Comets mention of the appearance of Comets about some of those times when, it is probable, this appeared, as within a year or two before and after; yet there is no way to determine which of these was the same as the present Comet.

Its next appearance was in 1380; but the time of the year is not mentioned. All the account is,† that "a burning Comet appeared in Aquarius for three "months together." From its appearing for so long time in Aquarius, we may conclude that it was in the winter; probably in the beginning of that year.

* Horrendæ magnitudinis. Lubienietski Historia omnium Cometarum, p. 251, 2.

† Lubien. p. 270.

It appeared a third time in 1456. The sum of the accounts then given of it are,* that "a Comet of an "unheard-of bigness was seen toward the east in the "middle of Cancer, the whole month of June, with a "tail of such a length as to reach almost two signs." By this it seems, the tail was much longer than it has been seen at any other time. But it is to be observed, that the Comet was then near its perihelion, where the tail is always largest; and the earth was in such a position as to view the tail almost directly, and therefore under the largest angle that can be. However, nothing is more likely than that the matter is exaggerated; most of the old descriptions of Comets being drawn up in very strong terms. Of which we have a signal instance in this very quotation, wherein the Comet is said to have been "of an unheard-of bigness." For these words refer to the body, and not to the tail of the Comet; as is plain in the original,† "Cometa inauditæ magnitudinis apparuit, cum prælonga cauda." Now the bigness of its body could scarcely deserve such an epithet; as we just observed, under its first appearance. Whether the same Comet may emit a longer tail in some revolutions than others, is a matter which, I suppose, has never been inquired into.

Hitherto the accounts are very defective; and we can learn nothing from them, of the Comet's course in the heavens.

* Lubien. p. 292.

† Hevel. Cometogr. Lib. viii. p. 461.

But the next time it was seen, which was in 1531, its course was observed, though imperfectly, by APIAN, one of the most learned astronomers of those days, but furnished with very indifferent instruments. He it was who discovered,* that the tails of Comets are turned from the Sun; and made only such observations on this Comet, as served to establish that discovery. It is said † to have been "seen from the 6th of "August, till the 3d of September, in the N. W. at "first in the morning before sun rise, and afterwards "in the evening after sun set. It went through Leo, "Virgo and Libra; going sometimes 4° in a day, "sometimes 5°, and sometimes 6°. It had north "latitude, which was daily decreasing." It is also said,‡ that it was a bearded "star, of a reddish or "rather yellow colour." From APIAN's observations of its course, Dr. HALLEY computed its parabolic trajectory;—that its proper motion in it was retrograde; though its apparent motion was direct;—and that it was in perihelion, August 25.

Its fifth appearance was in 1607, when its course was observed by the famous KEPLER with greater care than it had been before. The substance of the accounts, as we find them in HEVELIUS § and LUBIENIETSKI,|| are, "that it was seen 41 days from the "16th of September; at first in the evening, and af- "terwards all night;—that it had a very small paral- "lax, and so was no sublunary vapor, but elevated

* Hevel. Cometogr. Lib. viii. p. 461. † Lubien. p. 33.
‡ Hevel. Lib. xii. p. 846. § p. 871. || p. 407.

" to a great height in the æther;—that it proceeded " with a direct motion through Libra, Scorpio and " Sagittarius; at the end of September very swiftly, " not less than 13° in a day, but more slowly before " and after; and near the time of its disappearing, " being almost stationary;—that its face was spotted " and not round;—that it was larger than all the fixed " stars, and almost as large as Jupiter himself;—that " its light was weak, pale and watery, like that of the " moon, when near the shadow of the earth;—that " toward the end of its appearance, its head was more " and more diminished;—that its tail was about 7° " long, and projected opposite to the sun, though with " some deviation;" and lastly, that, agreeable to the terrific manner of describing Comets, which was not yet laid aside, " it appeared like a fiery spear or flam- " ing sword." From its apparent course, which KEPLER had particularly described for every night in which he observed it, Dr. HALLEY determined its trajectory; fixing the time of the perihelion to October 16.

Its sixth appearance was in the year 1682, when its motion was observed with all possible exactness by the best astronomers in the world, and with the best instruments; telescopes having been then applied to the making astronomical observations. It was seen from the 15th of August to the 9th of September; at first in the morning, afterwards in the evening. Its apparent motion was all the while direct, through Leo, Virgo and Libra. In the beginning it was accelerated, until it became almost 6° in a day; after that, it was retarded, till towards the end it was not more than 2° in a day.* It had north latitude, which at first increased till it was above 26°, and then decreased to less than 9°. Its head was brighter and somewhat larger than the famous one of the year 1680, but its tail not near so long. By Mr. FLAMSTEED'S observations at the Royal Observatory in *Greenwich*, the nucleus was hardly a tenth part so broad as the atmosphere surrounding it; which being measured by a micrometer was 2′; and therefore the nucleus was only 11″ or 12″ in diameter.† HEVELIUS found its tail, when longest, to be about 15° or 16°; but toward the end it daily diminished; and it deviated from the precise point of opposition to the sun. By Dr. HALLEY'S computation of its trajectory, it came to its perihelion September 4th.

Of its seventh appearance we ourselves are eye-witnesses. It was first seen, in this part of the world, on the 3d of April in the morning; but might have been seen much sooner, had not an uninterrupted succession of cloudy weather prevented it. On the 4th, at 3¾h, I saw it, low in the east and not very bright, with a tail about 3° or 4° long, directed obliquely upward, toward the S. W. It was then in about 26° of Aquarius, with 4° of north latitude. From hence it went westerly, or with a retrograde motion; and southerly withal, approaching toward the ecliptic, which it

* Lowthorp's Abridg. Phil. Trans. Vol. I. p. 447.

† Newt. Princip. p. 481.

crossed on the 11th. At first it moved not above half a degree in a day; but with a motion greatly accelerated, by reason of its coming almost directly towards the earth, it passed from the middle of the back of Aquarius, over the tail of Capricorn, and ran so far southward by the 22d, as not to rise above our horizon. While it was invisible to us, it might be seen in the southern countries, going over the tail of Pavo, and south of Triangulum Australe, and through the Crosiers, within 20° of the south pole of the equator. After it had passed its nearest distance from the south pole, the direction of its apparent motion must of necessity become northerly; by which means, it rose again above our horizon on the 27th. The last time I saw it before it left us, on its southern progress, was on the 19th in the morning; and the first time after its return, on the 29th, in the evening; when it appeared bigger than before, though not so bright, but rather of a dull and gloomy aspect; and its tail was longer and broader, seeming to be about 7° long and directed toward the east. These alterations were owing to its being nearer to the earth, and farther from the sun.* Its apparent course was now N. W. toward that part of Hydra, which is under Crater; and it crossed Hydra in about 15° of Virgo. As it was now going farther both from the earth and the sun, its motion became slower, and its bigness and brightness were continually diminishing. The last time I saw

* See above, p. 25.

it, before the writing of this, was on the 22d of May in the evening, when at 9 h $\frac{1}{4}$, I found it on the limb of Sextans Uraniæ, in about 8° of Virgo, and in 14° of south latitude; with some uncertainty, arising from the faint appearance it made; which will increase so as, in a little time, will make it difficult to find the Comet, especially when the moon-light nights come on. Its diurnal motion is now scarcely one quarter of a degree. Its apparent motion has all this while been retrograde, as well as its real motion; whereas in its former returns, its apparent motion was direct. This difference is occasioned by the earth's being now on the north side of the Comet's orbit; whereas before, it happened to be always on the south side. But the calculations made on the orbit of 1682 agree as well with the last observations we have made of the Comet, as they did with the first; and this agreement proves, both that it was the same Comet which appeared the beginning of April in the morning, and the end of April in the evening; and that this is the same Comet as that of 1682.

Such has been its course as seen from the earth. If the reader be desirous to know the principal *stages* of its present journey, they are as follow. In December 1720, it was in its aphelion, or greatest distance from the sun;—of above 28 hundred million miles. From that time it approached the sun; very slowly at first, but with a motion continually accelerated. Two years and a half ago, it entered the sphere of Saturn; that is, came as near to the sun as Saturn is; and the beginning of March 1758, it entered the sphere of Jupiter. It was in its ascending node about the middle of December last; being then beyond the sphere of Mars, which it entered on the last of that month; as it did the sphere of the earth on the first of February. Possibly, in the beginning of January and for some time after, it might have been seen in the western hemisphere in the evening, at first not far from the point of the vernal equinox, and then to the west of it; if one had known exactly where to look for it. At that time it was as near the sun as it was on the 22d of May, but not so near the earth; and therefore not bright enough to make people in general take notice of it. On the 10th of February, it was got to that point of its orbit where KEPLER first saw it on the 16th of September 1607; which is the most eastern point that we have any account of its having been seen in; as that on the 22d of May inst. is the most western. On the 20th of February it entered the sphere of Venus; but never went so low as that of Mercury. On the last of February, it was in conjunction with the sun, with but little more than 6° north latitude; and was then hid in the sun's rays. But by its retrograde motion it soon got to the westward of the sun, and came to its perihelion March 12; its distance from the sun being then almost 47 million miles. Its geocentric place was then in 5° of Pisces, with a little above 6° north latitude, as before. At that time, or soon after, it might undoubtedly have been seen in the east; for it rose 1h. 10′ before the sun. On the first of April it went out of the sphere of Venus; on the 11th, passed its descending node; and left the sphere of the earth, on the 20th. It came to its perigee or nearest distance from the earth, on the 25th; which was about ten million miles. It was in opposition to the sun, the 26th, having about 50° south latitude. At this time its diurnal motion was about 17°. It left the sphere of Mars the 23d of May; and will leave that of Jupiter about the middle of next March, and that of Saturn in September 1761; continuing its course through the southern parts of the heavens till the year 1834, when another visit may be expected from it.

To compare its different periods, it will be best to place in one view its several appearances, and the times of its perihelion, so far as we know them.

	Years.	Months.	Periods.
1.	1305,	April,	
2.	1380, about	Jan. probably,	74 Years, and about 10 months.
3.	1456,	June,	76 —— and about 5 months.
4.	1531,	August 25,	75 —— and two months.
5.	1607,	October 16,	76 —— and 52 days.
6.	1682,	September 4,	74 —— and 323 days.
7.	1759,	March 12.N.S.	76 —— and 178 days.

Upon this view it is obvious, that the periods of the Comet have been alternately greater and less; though the three first cannot be exactly determined. The last seems to have been as long; and the last but one, as short as any; the difference between them being a year and 220 days. This seems a great difference when compared with the small irregularities which the revolutions of the planets are subject to;* but

* See above, p. 23.

perhaps, when we know more of Comets, it may appear inconsiderable.

To find the mean revolution, we cannot come to any greater exactness, than by supposing that in 1305 it was in its perihelion at the same time of the year as it was this year; for both times it appeared in April. Therefore in 454 years it has made six revolutions; which gives $75\frac{2}{3}$ years for a mean revolution. Whence, supposing the earth's distance from the sun to be of 100 parts, we find, by KEPLER's rule,* the longer axis of the Comet's orbit to be 3578 of those parts; and its perihelion-distance being 58, its aphelion-distance is 3550. Thus the Comet's least distance from the sun is to its greatest as 1 to above 60. In the perihelion, the sun's diameter would appear to the Comet almost double of what it does to us; but in the aphelion, the sun would not look bigger than Jupiter and Venus in perigee do to us. And the sun's light and heat being reciprocally as the squares of the distances, the light and heat at the Comet in its perihelion is above 3600 times greater than it is at the aphelion. The Comet's angular velocities are also in the same proportion. In its aphelion it moves but 18′ of a degree in a year: whereas in its perihelion it runs through an equal angle in 2 h 24′. It continues on the north side of the ecliptic, where its perihelion lies, but 114 days; and spends on the south side all the rest of its long revolution.

* Page 23.

As to the real bigness of the nucleus—Mr. FLAMSTEED in 1682 found it but 11″ or 12″ in diameter, as was remarked before, p. 45, which is very nigh the bigness that Mercury appears of in his transits over the sun at his ascending node: And the Comet's distance from the earth at that time could not differ much from the planet's. Therefore the Comet may well be supposed to be about the same bigness as the planet Mercury, which is the least of all the planets, and but $\frac{1}{27}$th part so big as the earth. If we could find on what day Mr. FLAMSTEED made his observation, we might determine this point with greater exactness.

The tail was of an enormous length, by the account given of it in 1456. But the later accounts are probably exacter; of which the most distinct I can find is that of HEVELIUS before cited,* who in 1682 found it about 15° or 16° long. According to this, its real length was almost 12 million miles; which is long enough to reach from the descending node beyond the earth's orbit. So that if the Comet had come to that node about a month later, this year, or more exactly on the 14th of May, the earth would have passed through the end of its tail.

With regard to this Comet I shall only observe farther, that the ascending node of its orbit lies pretty near the orbit of Mars; and the descending, near that of Venus. After the ascending node, it may possibly come within about 12 million miles of the earth; and after the descending within 5 millions; as it

* p. 45.

would have done this year, had it come to its descending node but nine days later than it did. And these are the nearest approaches which it can possibly make to the earth.

We have not the like evidence of the return of any other Comet, as we have of this. Dr. HALLEY was inclined to believe that the Comet of autumn 1532 described the same orbit with that which was observed by HEVELIUS in the beginning of the year 1661; and if so, its period was of $128\frac{1}{4}$ years. * Though he remarks that APIAN's observations, which are the only ones extant of the first, are not exact enough to decide with certainty so nice an affair. What makes it probable to me is, that on looking into the histories, I find Comets appearing in those years, which a period of about 128 or 129 years, reckoned backward, falls upon. LUBIENIETSKI speaks of one that was seen in the end of March and beginning of April 1403; which was $129\frac{1}{2}$ years before that of 1532, and might probably be the same. He speaks of another in July and August, 1273, which was $129\frac{2}{3}$ years before the last mentioned; and of another in May, 1145, which was $128\frac{1}{6}$ years before that; and of another, which appeared for four months in 1017, or about 128 years before the last mentioned. But as I find none in the period next before this, it is needless to look farther back. The differences of these periods, being not greater than what we found in our present Comet, are no objection to all these Comets being the same;

* Phil. Trans. No. 297.

though, as we have no account of their courses, one cannot positively affirm that they were. If they were, its mean period is $128\frac{4}{5}$ years; and it will return in the year 1789, or 1790.

So far as an argument might be drawn from an equality of periods and from similar phænomina, * Dr. HALLEY thought that the period of that wonderful Comet of 1680 might be 575 years. Sir ISAAC NEWTON, from the curvature of its path, judged its period to be above 500 years;† and the learned Doctor, having found mention in history of four appearances of famous Comets, with remarkably long tails, after intervals of 575 years, was ready to conclude that these were the same Comet. The appearances were, in September after the death of JULIUS CÆSAR, 44 years before the Christian æra; in the year 531, in the reign of the emperor JUSTINIAN; in February 1106, in the reign of our K. HENRY I; and in December 1680. The Doctor added "similarity of phænomina;" being sensible, without doubt, that the argument drawn from the equality of periods can, by itself, have no great force. For so frequent have been the appearances of Comets, that a number of imaginary periods might easily be assumed, which, reckoned in order, for three or four successions, might fall on years wherein Comets were seen. It is pity the Doctor could meet with no account of the courses of these Comets in the heavens; which might have decided the question with certainty on one side or the other.

* Synops Astron. Comet.

† As above, p. 25.

Since his death, a manuscript has oeen found in the library of Pembroke-Hall in *Cambridge*, which gives some, though a very imperfect account of the course of that Comet which appeared in 1106. And the Author,* who mentions it, observes, that "there is such "a wide difference between this manuscript account "and the Comet's places computed on the orbit of "1680, as must very much lessen, if it does not quite "overbalance, the force of the arguments brought by "Dr. HALLEY to prove the identity of these two "Comets."

This manuscript gives also a short account of a famous Comet which was seen in 1264. So far as its trajectory could be determined from that slender description, there is found such a resemblance between it and that of the Comet of 1556, as gives some ground for conjecture that they might possibly be the same. If they were, its period is 292 years; and it may be expected about the year 1848.

This is the substance of what we have collected in regard to the revolutions of Comets. Our knowledge in this article is very imperfect; but we are now in the right way to have it enlarged. Every Comet that appears will either increase the number of Comets, or discover the period of some one that was unknown. As the number of Comets increases it may be best to distinguish them by names. Hitherto, each has been known only by the year of its appearance; as the Comet of 1680, or that of 1682,

* Mr. Dunthorne in Phil. Trans. Vol. xlvii. Art. xliii.

&c. But perhaps it may be more convenient to range them in numerical order, as the astronomers do the satellites of Jupiter and Saturn; reckoning those first, whose periods are shortest. In conformity to which way of speaking, our present Comet is doubtless the *first* Comet; and that of 1661 may probably be the *second.* It is natural to expect that the periods of others will be discovered in nearly this numerical order; for the shortest are likely to be discovered soonest. But it will require the observations of many hundreds, if not thousands of years, to complete the Cometic system.

THE END.

ESSAY

ON COMETS.

IN TWO PARTS.

PART I.

Containing an attempt to explain the phænomena of the TAILS OF COMETS, and to account for their perpetual opposition to the SUN, upon philosophical principles.

PART II.

Pointing out some important ends for which these TAILS were probably designed: Wherein it is shewn, that, in consequence of these curious appendages, COMETS may be inhabited WORLDS, and even comfortable habitations; notwithstanding the vast excentricities of their orbits.

The whole interspersed with observations and reflections on the Sun and primary Planets.

BY ANDREW OLIVER, JUN. ESQ.

In human works, though labour'd on with pain,
A thousand movements scarce one purpose gain;
In God's, one single can its end produce;
Yet serves to second too some other use.

Pope's Essay on Man.

BOSTON,

PUBLISHED BY W. WELLS, AND T. B. WAIT, AND CO.

T. B. Wait & Co......Printers.

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1811.

TO

JOHN WINTHROP, LL. D.

Hollisian Professor of the Mathematics, and Natural Philosophy, and Fellow of the Corporation, of Harvard College: Member of the American Philosophical Society of Philadelphia; and Fellow of the Royal Society.

THE FOLLOWING ESSAY,

As an acknowledgement of the obligations which result from an initiation, under his instruction, in the study of those sciences which more immediately belong to his province: In reliance upon his patronage of a Treatise, which owes its publication to his candour and approbation: and, with all due deference to his superior judgment; is gratefully inscribed, by

His obliged friend,

And most humble servant,

THE AUTHOR.

PREFACE.

THE design of the following Essay was, partly to eradicate some absurd notions which have been handed down from the darkest periods of antiquity, and which are still entertained by some, upon the appearance of a Comet; and to remove the apprehensions which may have been excited in the minds of others, even by the writings of some great men among the moderns: And partly to offer to those who indulge themselves in more abstruse researches after the operations of natural causes, a few hints, the prosecution of which may enlarge the field of philosophical speculation, and open to all a new source for adoration of the wisdom and beneficence of that Being, who has made nothing in vain, and has disposed the various parts of the universe by *weight and measure.* It may therefore be presumed, that, if the author is so happy as to be understood by the generality of his readers (which he has aimed at throughout the whole) the gentlemen of science will pardon those minute discussions, which *they* may judge unnecessary, and that they will weigh with impartiality the arguments which may be offered for their consideration, overlook any immaterial inaccuracies, which may have arisen

6

through inadvertency, and point out and refute with candour any mistakes which *he* may have fallen into.

It is now well known to astronomers that the motions of Comets are regulated by the universal law of gravitation, and that they regard the sun as the common centre of all their motions, equally with the planets, although they are more numerous, and apparently distinct in species from them. The planets, since the discovery of the *Satellites* or *Moons* which attend some of them, are generally, and with the highest reason supposed to be inhabited worlds like the earth.—Whereas it has been thought even by some of the greatest modern astronomers, that the extremes of heat and cold to which Comets are alternately exposed in the different parts of their orbits, are irreconcilable with the notion of their being fit habitations for any material race of beings whatever. They are to this day regarded by the bulk of mankind, either as *portentous meteors*, exhibited only to threaten war, famine or pestilence to the inhabitants of the earth; or as *fiery globes* which move through the heavens at random, and might fortuitously come across the earth in its way, to its no small detriment, if not to the destruction of its inhabitants; or lastly as *penal worlds*, ordained to a perpetual chaotic state, whose inhabitants are condemned to be frozen and burned alternately, at their *aphelia* and *perihelia*; agreeable to *Milton's* idea of the punishment of apostate spirits; speaking of whom he says,

"They ———————— feel by turns the bitter change
Of fierce extremes, extremes by change more fierce,
From beds of raging fire to starve in ice
Their soft ætherial warmth, and there to pine
Immoveable, infix'd, and frozen round
Periods of time, thence *hurried* back to fire."

PARADISE LOST, Book II.

The first of these opinions was exploded long ago by *Seneca;* who, instead of regarding Comets as transient meteors, on the contrary ranks them with "the eternal works of Nature." The second directly contradicts the idea of a divine superintendency, and falls of course, in the minds of those who entertain any just apprehension of the providential care of the great Author and Governor of the Universe. And as to the last, with what colour of reason can we suppose that the Creator would provide upwards of fifty worlds (for so many different Comets and more there certainly are) solely for the punishment of the incorrigible inhabitants of five or six planets only? On the contrary does it not redound more to his honour, to consider these bodies as so many inhabited worlds, provided with every necessary for the comfortable subsistence of innumerable inhabitants, rational and irrational, like the earth? Or as Doctor *Young* (speaking of the Creator and his works) beautifully expresses himself;

"Darts not His glory a still brighter ray,
The less is left to *Chaos* and the *Realms*
Of hideous Night?————

NIGHT THOUGHTS, Night 9.

The reader will find (in the introduction) that the consideration of the subject, in this light, was first started by *Hugh Williamson*, M. D. of *Philadelphia*, in a treatise that was published in one of the weekly papers; which, as it contained some new thoughts, the pursuit of which (it was judged) would tend to the improvement of natural philosophy, first induced the author to undertake the following essay, upon a subject indeed which, till then, he had but little attended to: he therefore hopes that, if any observations or reflections shall turn up, in the course of it, which may merit the attention of his readers, and may have escaped the notice of others, they may in some measure atone for the many defects, of which he is apprehensive, and which are submitted to those who have made greater proficiency in natural knowledge, than he pretends to, to rectify.

Divers of the author's friends, who are gentlemen of speculation and learning, perused the essay in manuscript, upon whose approbation of it, and at whose request, he was induced to consent to its publication: but when the unexpected number of subscribers, and their respectable characters in general, came to his knowledge, his diffidence of its title to their favourable reception was naturally increased, which would have excited in his mind a proportionable reluctance to its appearance abroad, lest their expectations should be disappointed, had he not been fully persuaded, that the greatest candour was naturally to be expected from those who are the best judges of the subject; especially, as the treatise contains nothing more than an attempt to discover some philosophical truths, the knowledge of which may tend to promote the cause of science, and thereby may possibly be of some service to mankind.

It was with pleasure he found that Doctor *Gowin Knight*, F. R. S. had attempted to account for the phænomena of the tails of Comets from the same principle which he has endeavoured to establish in the following pages, viz. a mutual repellency, subsisting between the atmospheres of the heavenly bodies: as the Doctor, when he wrote his treatise, was engaged in the general solution of all the phænomena in nature, by the help of two universal principles, viz. attraction and repulsion, he but slightly touched upon the particular phænomena, now under consideration; accordingly what he says upon the subject is very short, being included within the compass of a single corollary, which arises out of a long chain of deductions from the *supposed* properties of an *imaginary* repellent fluid, uniformly distributed *throughout the infinity of space;* the existence of which, however probable, has never been proved. When the author wrote that part of the essay which is confined particularly to this subject, Dr. *Knight's* solution was entirely out of his mind, if he had ever seen it before. He therefore took a different course to establish the principle, deducing it from the *known* properties of air, a *real* fluid, the existence of which we are *certain* of, from the *immediate testimony of our senses*, as we are of its properties from *innumerable experiments.* This element differs essentially from the Doctor's universal fluid, which indeed he supposes to consist of particles mutually repellent, like those of air, but so inconceivably rare, that a quantity of it sufficient to fill the whole space occupied by the solar system, might not weigh one single grain (Knight's Essay, page 15): air on the contrary, is a heavy fluid, the pressure of which, merely from its gravity, is capable of giving great pain to those who may attempt to sustain its weight, in pneumatical experiments.

However, it does not follow, that if air, considered as a fluid *sui generis*, is sufficient *immediately* to account for the phænomena before us, we should therefore exclude the agency of another, upon whose existence and properties (if proved) the properties of air itself may possibly depend. By supposing such an universal *repellent* fluid, Doctor *Knight* has very curiously accounted for many of the phænomena of nature, which are so common as to be but little attended to; such as *fluidity*, *elasticity*, *magnetism*, &c. And, whether the mutual repellency of the particles of air does (as he supposes) or does not depend upon the presence of the same fluid, the conclusion will equally follow that, *The ærial atmospheres of the heavenly bodies are mutually repellent.*

INTRODUCTION TO THE ESSAY.

In the month of September, 1769, during the appearance of a remarkable Comet, Doctor *Hugh Williamson* of *Philadelphia*, favoured the public with a treatise on the subject of the following essay, which was read before, and published by order of the Philosophical Society in that city. This piece contained some curious hints, well deserving the attention of the friends of science: particularly, that Comets, as well as the planets, may be *habitable worlds*; that the comfortable state the inhabitants of the various globes of the solar system enjoy, may not depend merely upon their several distances from the sun; and, that although the rays of the sun may be absolutely necessary to the very existence of planetary heat, yet the temperature of that heat may depend upon the densities of the atmospheres surrounding the several globes; whereby the Comets, even in their aphelia, may be rendered comfortable habitations, by means of the vast atmospheres which attend them, and which, when they might become detrimental to their inhabitants, as when they are in the neighbourhood of the sun, are, by the momentum of the sun's rays, or by some other cause, thrown off to immense distances behind them.

The perusal of this treatise occasioned the following attempt to establish the doctrine of the habitability of Comets, advanced therein by Dr. Williamson.

We differ indeed in our hypotheses to account for the phænomena of their tails; but whichsoever may be the true one, all *his* conclusions, relative to the densities of their atmospheres in the various parts of their orbits, may equally follow.

The Doctor's hypothesis, which is the same with *Kepler's*, supposes the atmosphere of a Comet, by the velocity and consequent momentum of the sun's rays, to be propelled through immense spaces behind its body, whereby the tail is formed, which is rendered visible by reflecting those rays.

This, it must be confessed, seems to be as natural and easy a solution as any one hitherto offered; and might be embraced as such, had any one experiment ever been produced to prove the rays of light endued with any such power, even upon the most minute corpuscles, or the most rarefied vapor. Sir *Isaac Newton* passes it by with little more than a bare mention, (Princip. under prop. XLI. Book III.) which, as it is so plausible, is difficult to account for; especially as he fills pages to refute others, that are almost self-evidently absurd. This hypothesis, however, has never been confirmed by any one experiment, although an age has elapsed since *Kepler's* time, during which experimental philosophy has been at its zenith. Therefore, as Mr. Professor *Winthrop*, in his lectures on Comets, observes, "much stress "should not be laid upon it, as we know of no parallel "instance in nature to support it." The hypothesis, contained in this Essay is founded upon a mutual repellency, which is supposed to subsist between the several atmospheres of the heavenly bodies; which is deduced from the repellency of the particles of air, of which the atmosphere of the earth, and those which surround the other globes, are composed. That our atmosphere consists of particles thus repellent, is certain from the whole system of pneumaticks, as no one experiment, in that useful, instructive and entertaining branch of natural philosophy, can be performed, which does not depend upon this property of AIR. That the sun and planets have similar atmospheres, will appear in the following pages.

Sir *Isaac*, after having refuted several hypotheses, which had been raised by others, to account for the ascent of Comets' tails from the sun, at length rather hints at, than substitutes one of his own; as he asserts nothing positively, but only offers a quere for the consideration of his readers. Therefore it is hoped that nothing here advanced will be considered as a *vain, rash* attempt to confute that illustrious author. "The "ascent of smoke in a chimney (says he) is owing to "the impulse of the air with which it is entangled. "The air, rarefied by heat, ascends because its specific "gravity is diminished, and in its ascent carries along "with it the smoke with which it is engaged." (Princip. ubi supra.) To which he adds the following quere: "And why may not the tail of a Comet rise from the "sun after the same manner?" Previous to an answer to this quere, let us consider more particularly the causes of the ascent of vapours in our atmosphere. it is indeed beyond doubt, that to the cause above assigned, by Sir *Isaac Newton*, is in a great measure owing the rise of smoke from common fire; from which, if enkindled in the open air, it will curl up in broad volumes, spreading as it rises; but if confined in a chimney, the rarefied air having but one way to expand itself, viz. through the funnel, the more condensed air in the room below driving it upwards, together with the smoke engaged with it, it ascends in a straight course, with a greater velocity, and apparently to a greater height than when unconfined.

But this is not the sole, nor yet the principal cause of the ascent of vapours in general, but rather an accidental one, which increases their velocity when already on the wing. For, *really*, the *causa sine qua non* of their ascent, in a quiescent atmosphere, is the difference of the specific gravities of those vapors, and the air they float in;* the former, being generally lightest, continue rising till they arrive at that region of the atmosphere in which the densities of both are equal.—There they gather and form into clouds; there they remain suspended, or are driven by winds in directions parallel to the surface of the earth, until some casual rarefaction of the air, the meeting of contrary winds, or of electrified clouds differently charged, cause them, either to condense impercepti-

* How they are generated, and detached from the surfaces of bodies, is a proper subject for an inquiry by itself, but foreign here.

bly, and fall in dews or gentle rains, or to rush more violently together, and precipitate in showers, according to the nature of the cause by which they are actuated. The smoke of a chimney is for the most part lighter than the circumambient air it ascends through, otherwise it would descend again as soon as it could disengage itself from that column of air which carried it up; in consequence of which, life would be very uncomfortable in large, populous cities; for, at times, the air with us is so rarefied that the smoke does in fact thus descend, and hover just above the surface of the earth, to the no small annoyance of the eyes and lungs of those who breathe in such an impure medium. Were it necessary, experiments in pneumaticks might be recited, which prove that air, near the surface of the earth, is in general denser or heavier than the smoke and other vapors which float therein; which are here omitted, as it is presumed the fact will not be disputed.

Now, if the tail of a Comet rises from its head, or rather from the sun, in the same manner as smoke does from fire with us, and from a similar cause, the æthereal medium, through which it ascends, must be nearly of the same density with the vapors of the tail; otherwise the latter could not float in, nor get so entangled with it as to be carried up thereby through distant regions of the heavens; but that the tails may ascend to such amazing heights, as some of them do, we must necessarily suppose their specific gravities much less than that of the æther itself.

What then becomes of the free celestial spaces? in which *Sir Isaac* says,—"not only the *solid bodies of "the planets and Comets*, but also *the extremely rare "vapors of Comets' tails, maintain their rapid motions "with great freedom——without resistance.*" (Ibid.) Soon after he adds, "—the tails—retaining their "own proper motion" (i. e. the motion they had in common with their heads) "and in the mean time "gravitating towards the sun, must be revolved in "ellipses round the sun in like manner as the heads "are, and by that motion always accompany their "heads." Now, although the æther may be supposed so extremely rare, as that the solid globes may revolve through it for many ages, without any sensible impediment, or, as *Sir Isaac* says, "above ten thousand years;" yet, as the tails must, upon this hypothesis, be nearly of the same specific gravity with that æther, how can *they* "maintain their rapid motions "through it *without resistance*, and revolve in ellipses "round the sun together with their heads?" That this is utterly impossible, appears from the reasoning of *Sir Isaac himself*, throughout the whole of his VII section *Principia Book II.* intituled, *Concerning the motion of fluids, and the resistance made to projected Bodies:* According to which reasoning the projectile motions of these vapors would be very soon destroyed, and the Comet in its regress from the sun would necessarily leave them behind as they rose from the head, in consequence of the resistance of this æthereal medium: Therefore, whenever the Comet became visible, after the perihelion, it would have a tail as before, but *reversed*, appearing, like a lucid beam, to stream away from the head *towards* the sun, till it were confounded with the twilight. But this is contrary to all observations; for the projection of a Comet's tail, after its perihelion as well as before, is both really and apparently *from* the sun, excepting a small deviation towards the parts from whence the Comet last came: Which deviation is by no means owing to the resistance of any medium it passes through, but is perfectly consistent with its several parts retaining the motion they had in common with their head when they began to ascend, and "revolving *freely* in ellipses "round the sun together with their head." For, the remote parts of the tail making a larger sweep through the heavens than their head, while the latter takes a shorter turn round the sun at its perihelion, must necessarily be longer in describing the same angular motions round the sun than the globe itself; consequently must be deflected from the direct opposition to the sun, and the whole tail be incurvated towards the perihelion position lately passed; and this upon the supposition that both head and tail move *freely* through a perfect *vacuum*. This incurvation of the tail lessens as the Comet recedes from the sun, until at length it recovers its opposition as at first. Now, as these phænomena agree perfectly with the motion of a Comet's tail through spaces *void of resistance*, they are utterly inconsistent with the supposition of its moving through a medium of equal or greater density than itself, or in any other *resisting medium* whatever; for according to this celebrated author (Princip. Sect.

VII. Book II. Prop. XXXVIII. Cor. 4.) if the head or solid globe of the Comet moved in a fluid of the same density with itself, it would lose half its motion before it could describe the length of two of its diameters, consequently it would soon lose the whole. The vapors of the tail rising (upon his hypothesis) in a medium of nearly the same density with themselves, would in like manner, from the resistance of that medium, lose all the projectile motion they derived from the head, full as soon as the head would lose its own motion in the former case.

Sir *Isaac* concludes said VII section with the following words, "The *resistance* in every fluid is as "the motion excited by the projectile in the fluid; "and *cannot be less in the most subtile æther, in proportion to the density of that æther, than it is in air, water, and quicksilver, in proportion to the densities of those fluids.*"

Upon the whole, then, it necessarily follows, that the æthereal spaces through which the *extremely rare vapors of a Comet's tail revolve freely with its head in ellipses round the sun*, must be perfect *vacuums* as to all the purposes of *resistance;* and consequently, that the rays of light themselves in no wise impede the freedom of their motion, even when in the neighbourhood of the sun.

All that is desired of the reader is, that he will peruse the following sheets with candor, and not pronounce sentence until he has fairly weighed the evidence produced in support of the several propositions therein contained; upon the strength, or through the deficiency of which, they must stand or fall.

ESSAY ON COMETS.

PART I.

A COMET consists of two parts which fall under our observation, viz. a solid, spherical, opaque body, which, like the planets, shines by reflecting the light of the sun, and no way differs in appearance from a planetary globe; this is by astronomers called the *nucleus:* Also a very extensive atmosphere; which, from the form it usually exhibits to us, is called the *tail,* and commonly exhibits a faint beam of light, which diverges as it recedes from the head, and often apparently extends through distant constellations, when it nearly resembles those momentary corruscations which shoot upwards from the horizon towards the zenith, during the appearance of an *aurora borealis,* or northern light. This tail increases in length as the Comet approaches the sun, *et vice versa;* and its direction is always nearly in opposition to the sun. Sometimes indeed the cometic atmosphere assumes a different form, surrounding the nucleus equally on every side like a thin cloud or mist, or, as some have fancied, like a bush of hair; whence the Comet has been denominated *crinite* or hairy. The latter is the usual appearance of a Comet when first discovered in its descent toward the sun, provided the sun and Comet be in opposite hemispheres; and may take place in some other situations, agreeable to the rules of optics, even when to spectators in other parts of our system, the Comet may exhibit a tail of an enormous length.

It has been sufficiently demonstrated by Sir *Isaac Newton*, Dr. *Halley*, and others, that these bodies are, in common with the other globes of the solar system, subject to the law of mutual gravitation, and that they regard the sun as their common centre of gravity, and consequently move round him in *conic-sections*, carrying their atmospheres or tails along with them. Their orbits differ widely from *circles* on the one hand; on the other, since the discovery of the Newtonian method of computing their trajectories from observations, they have never been found to deviate into *hyperbolas;* and though their observed places, in the small parts of their orbits in which they are visible to us, agree with their computed places, upon the supposition that they move in *parabolas;* yet, as the periodical revolutions of some of them have been ascertained by their regular returns after certain intervals, it is agreed by astronomers, that their paths are truly *elliptical*, though very excentric; such *ellipses*, near the extremities of their transverse axes, differing but insensibly from *parabolas*. All that is attempted in this Essay, is,

1. To account for the phænomena of the tails of Comets, upon philosophical principles: and then,

2. To point out some ends to which they seem adapted, and for which they are probably designed.

Sir *Isaac Newton* has sufficiently proved that these tails consist of a fluid matter, extremely rare, emitted from their heads upon their approach to the sun, which is rendered visible by reflecting his rays :* But what cause there may be existing in nature, capable of projecting the cometic atmospheres through such immense spaces, is a question which still remains to be solved, no satisfactory account having hitherto been offered to the public. In order therefore, to a rational solution of this curious phænomenon, *the tail of a Comet*, the following propositions, observations, &c. are submitted to the candid perusal of the reader: First premising, that when a subject, under consideration, is in its nature purely physical, it is to be presumed that strict, mathematical demonstration will not be expected.

We shall now endeavour to prove the following propositions.

First, That the primary planets, the Comets, and the sun, are all surrounded with atmospheres.

Secondly, That these atmospheres consist of the same fluid with the atmosphere of the earth, viz. Air.

Thirdly, that they are mutually repellent to each other; as the globes they surround are in a state of mutual attraction or gravitation.

I. As the proof of the existence of the atmospheres of the sun, planets and Comets depends upon

* Princip. Book III. under Prop. XLI.

a variety of astronomical observations, it is necessary to be particular as to each of them.

And, 1. That the *earth* we inhabit (which is a planet vastly inferior, both in bulk and situation, to some others) has one, we have the best evidence possible, viz. the testimony of our senses; besides, we all know, that the air, which every where surrounds the earth, is essential to the breath of life.

2. That *Mars* has an atmosphere, and that very extensive, has been demonstrated from the occultation of a fixed star by that planet;* as the star vanished at a distance from, or without ever arriving at a visible contact with his limb; as was observed by *Cassini*, October 1st, 1662. The like was observed after the same occultation, by M. *Roemer*, at Rome, the star not being visible after the transit till at a distance from his limb.

3. *Jupiter's* belts are in a fluctuating state, as they frequently vary their form, size, and situation;† which cannot be accounted for, unless we suppose them to be clouds and exhalations, floating in an atmosphere which surrounds his globe.‡

4. Some belt-like appearances were discovered in *Saturn* by Mr. *Hadley* through his five-foot reflecter, and by Mr. *Pound* through *Hugenius's* glass, though they appeared very faint, as he is so remote;§ which

* See Smith's Opticks, vol. ii. page 430.

† Idem, page 433.

‡ Sir Isaac Newton says these belts "are formed in the clouds of that planet." Princip. book iii. Lemma Prop. xxxix.

§ S. Opt. page 441.

belts are probably in the same fluctuating state as those of *Jupiter*, and arise from similar causes.

5. That *Venus* has an atmosphere may also be inferred from the variable spots which have been observed upon the face of that planet,* which are probably of the same kind with the belts of Jupiter, or the clouds which float in our own atmosphere, and, consequently, have a similar one to sustain them.† But for proof of its existence we need go no further back than the late transit of Venus over the sun's disc, *anno* 1769; when the atmosphere itself was visible, and that in different situations, to observers in distant parts ‡

6. *Mercury* is too near the sun to favour us with such observations; but if we suppose his globe inhabited, he doubtless stands as much in need of an atmosphere as any other planet, and has as important purposes to be served thereby.

7. That the Comets are surrounded with atmospheres is already taken for granted, because self-evident. Sir *I. Newton*, from various observations, concludes that their diameters are, one with another, at

* Idem, page 421.

† Were these belts, spots, &c. really adhering to, and parts of their respective globes, they would always appear invariably the same, in the same situations, as those of the moon do; in which no atmosphere has yet been discovered.

‡ See Transactions of the American Philosophical Society of Philadelphia, page 42. Also Observations by Mr. Benjamin West at Providence, N. E. page 16.

least equal to ten diameters of their nuclei or solid globes.*

8 That the sun has an atmosphere, and that proportioned to his amazing magnitude, is rendered highly probable by the macular appearances, or spots frequently discovered upon his disc : Which, as they often suddenly break out, and as suddenly disappear, and sometimes vary their shapes, even when under the eye of the observer; can be no other than huge clouds of smoke, or other vapours floating in such atmosphere ; huge indeed ! as they frequently exceed the whole superficies of the earth. Mr. *Derham*, who was peculiarly assiduous in observing them, has assigned a cause, to which their phænomena accurately agree. He supposes them to be immense volumes of smoke, belched forth by volcanoes or fiery eruptions, which are frequently breaking out upon his surface.† These spots, when large, sometimes continue during a whole revolution of the sun round his axis, or about twenty-five days ; and it is from the regular returns of such spots to the same part of his disc again that this revolution has been determined. But such clouds, were they not supported by an atmosphere, would tumble down again upon the sun presently after the explosions which raised them were over, as we see vapours emitted in an exhausted receiver, for want of air to sustain them, sink down to the bottom of the receiver.

* See Princip. Book III. Prop. XLI.

† See Jones's Abridgment of Philosoph. Trans. Vol. IV. page 238.

II. We shall now endeavour to prove that the planetary, cometary, and solar atmospheres, consist of the same elementary fluid with the atmosphere of the earth, viz. AIR.

Air is a fluid, which when pure is transparent, and in the highest degree elastic, being indefinitely compressible and dilatable; which qualities are truly characteristic of it, as we know of no other fluid to which they belong.

It may be necessary to observe here, that upon our globe, which (as already observed) is itself a planet, the presence of air is necessary, both to the preservation of animal life, and to the existence of flame: For in a glass receiver, small animals die, and candles go out, immediately upon the air being exhausted; upon air also seems to depend the explosive power of enkindled vapours; for gunpowder itself, one of the most powerful agents hitherto invented by the art of man, if fired by an hot iron in vacuo, will consume away, but never flash, nor explode; and it is generally agreed by those who are acquainted with experimental philosophy, that this vivifying, inflammating quality of air, depends upon its elasticity, or the active, contrifugal power of its particles, to be considered under the next general head. This being premised, we proceed to prove,

First, That the atmospheres of the several globes of the system consist of transparent fluids: The truth of which will be sufficiently evident, if we consider the several phænomena by which they were discovered.

It has already been shewn that Mars is surrounded with a very extensive atmosphere ; which, had it not been transparent, must have escaped the notice of astronomers during the time of the occultation of the star before mentioned ; for were it opaque, it would, by reflecting the sun's rays, as well as by its want of transparency, have hid the planet itself, and by the observers have been confounded with it ;* in which case the moments of the occultation of the star, and of its visible contact with the limb of the planet, would have been the same ; whereas the disappearance of the star before any such contact could take place, is a demonstration of the refraction of its rays in a transparent medium, with which the planet is surrounded.

The changes which are observable in those fluctuating collections of heterogeneous matter, of which the belts and spots in the other planets, and the sun consist, for the same reason, could never have been discovered, were they not sustained in transparent fluids, above the surfaces of their respective globes.

The transparency of the cometic atmospheres is undeniable, as their nuclei are frequently seen through them, although they occupy spaces equal to many diameters of the earth ; and the smallest stars are visible through the tails which proceed from, and are

* In like manner, as Sir I. Newton concludes, (Prin. B. III. Lemma IV.) "that the earth, if it was viewed from the plan-"ets, would without all doubt shine by the light of its clouds."

only expansions of them ; in which tails we have ocular demonstration of a most surprising dilatability ; from whence their recompressibility and elasticity may be justly inferred.

Secondly, Although there are no observations in the records of astronomy which prove this elasticity in the planetary atmospheres; yet, as the planets are with the highest reason supposed to be inhabited worlds, the presumption is at least very strong, if short of a demonstration, that their atmospheres are designed to answer purposes every way similar to those which are effected by the atmosphere of the earth, and that they are endued with all those properties, which are, with us, necessary to the preservation of animal life; consequently that they are elastic, as well as transparent, and altogether like our air.

The atmosphere of the sun is, by his excessive lustre, hid from our view; but if we consider him as an immense flaming globe, kindled up to warm and enlighten the whole system, we may well suppose that he has a large share of that fluid, without which (as before observed) scarcely any flame can subsist with us for a moment. Some authors indeed are of opinion, and not without reason, that the sun is not a body of fire, as commonly supposed. Doctor *Knight* in particular, (in his curious treatise of attraction and repulsion, as two universal principles, by which he endeavours to solve all the phænomena in nature,) seems to be of opinion, that the inhabitants of the sun (if inhabited) are in as much danger of suffering from cold, as from excessive heat.* But of whatever substance the body of the sun may consist, Mr. Derham has, by his observations, put it beyond all reasonable doubt, that the *maculæ* and *faculæ*, or the darker and brighter spots observable at times upon the sun's disc, are really owing to the bursting of volcanoes; "the "*faculæ* being only the appearance of the flames, af- "ter the dense smoke attending the explosions is dis- "sipated, or removed to a distance from them."† Now there is no reason to doubt but that, upon our globe, air is as necessary to the flames of Ætna and the eruptions of Vesuvius, as to the smaller blaze of a candle, or to the explosion of gun-powder; may we not then rationally conclude, that it is equally necessary to those astonishing volcanoes in the sun?

It is now proved, as far as the proposition is in the nature of it capable of proof, that the celestial bodies are surrounded with atmospheres, and that these at-

* See said treatise, page 58; in which are these remarkable words: Speaking of the sun and fixed stars, he says, "Their "globes are no longer frightful gulfs of fire, but inhabitable "worlds: Those philosophers who thought them too hot for "the habitation of salamanders, and those sublimer genii, who "thought them to be hells, will now perhaps be in pain, lest "the inhabitants should freeze with cold."—However, Doctor Knight concludes from his own principles, that the sun has an immense aerial atmosphere condensed round him; for in the preceding page 57, he says, "The vast weight of the sun's at- "mosphere must make the density of the *air* so great near the "sun's surface, that what would create a sound scarcely audi- "ble with us, would there produce a very loud noise."

† See Jones's Abridgment of Phil. Trans. before cited.

mospheres consist of transparent elastic fluids, like the air surrounding this earth. It remains that we prove,

III. That the atmospheres of the sun, planets, and Comets are mutually repellent to each other; as the solid globes they surround are in a state of mutual attraction or gravitation.

It must here be observed; that in reasoning upon gravitation, the great author of the present philosophical system of the heavens argues downward from the greater to the lesser, from *worlds* to *atoms*; thus, finding by mathematical deductions, compared with astronomical observations, that all the globes of the solar system, sun, planets and Comets gravitate, or have a mutual tendency towards each other, and that this reciprocal attraction is proportional to the quantities of solid matter they respectively contain; he very justly concludes, that every single particle in any one of their solid masses both attracts, and is attracted by, every other particle of matter, contained in every globe throughout the solar system.*

But as the heavens exhibit no phænomena from which we can, directly and with equal certainty, infer the existence and universal extent of the contrary principle of repulsion, as subsisting between the atmospheres of the heavenly bodies; we are here obliged to use a contrary method, and to reason upward from the powers and properties which, by their ef-

* Principia Sparsim.

fects, we discover to belong to those parcels of air upon which we can make experiments; to the effects, which the same powers and properties would naturally produce, in those vast collections of air, which constitute the atmospheres of the several globes; and if by tracing the necessary operations of these powers, step by step, we can at length arrive at any of the grand phænomena of nature, we may with the highest reason conclude, that these phænomena are the effects of those powers.

We shall therefore endeavour to prove from authors of the best credit, or from experiments which any one may try at his leisure,

1. That there is a mutual repellency subsisting between the particles of air, whereby they continually endeavour to recede from each other; in consequence of which, that fluid is indefinitely dilatable from the centrifugal activity of its particles, as well as compressible by any foreign power.

The honourable *Robert Boyle*, Esq; found by experiments, that air might be so rarefied as to occupy 13769 times the space it fills when in its natural state near the surface of the earth;* other experiments prove, that it may be so condensed, as to be contained in $\frac{1}{60}$ part of the same space,† therefore multiplying 13769 by 60, it appears, that the cubic space it is capable of filling, under different circumstances, may be as 826140 to 1. But the cube root of 826140 is 94

* See Shaw's Abridgment of Boyle, vol. i. page 551.

† See Martin's Philosophical Grammar, page 178.

nearly; therefore the central distances of the particles from each other, as discoverable by actual experiment, may be as one to ninety-four, and that from their centrifugal activity.

Moreover, Sir *Isaac Newton* from experiments concludes this repulsive power to be so great, as that a cubic inch of air, condensed as it is with us, if removed one semidiameter of the earth above its surface, where it would be free from the pressure of an incumbent atmosphere, would so expand itself by virtue of this power, as to fill the whole sphere of Saturn's orbit; nay he adds, "and far beyond it."*

2. This mutual repellency of the particles of air is greatly increased by heat. For if a bladder not more than half filled with air, be tied up tight, and laid before the fire, the additional expansive power, which the air contained therein acquires from the heat, will swell the bladder to its utmost extent, and will at length burst it with an explosion.

3. The particles of air, although mutually repellent amongst themselves, are with regard to other matter, in the common state of gravitation or attraction. This is evident from their being condensed in the form of atmospheres round the solid globes of the system, and attending them through all their revolutions.

4. The mutual repellency of the particles of air is indefinitely greater, in proportion to the quantities of

* Princip. Book iii. under Prop. xli.

repelling matter, than the mutual attraction, subsisting betwixt the solid particles of attracting matter.

The truth of this proposition will appear, at least highly probable, if we consider that the quantity of matter contained in our air near the surface of the earth, and which gravitates in common with other matter towards its centre, is so small, though condensed by the whole weight of the incumbent atmosphere, that one quart of it weighs no more than eight grains, as appears from experiments; yet so great is the repulsive power of its particles, that a small quantity of it, condensed by art in the barrel of an air gun, of the size and bore of a common fowling piece, is sufficient, when permitted suddenly to expand itself through the tube, to discharge a musket ball, in the same manner as fired gun-powder, the noise excepted, and with the like fatal effects.

We shall now proceed to prove the following proposition, viz. If two corpuscles of matter be in a state of mutual repulsion at any given distance, as *A. B.* Fig. 1. where they repel each other with a given force, say = 1. and this repulsion decreases, either as the distances *Ac*, *Ad*, *Ae*, *Af*, &c. or as the squares, cubes, or any higher powers of those distances, increase, the extent of that repulsion is indefinite.

For suppose *A* and *B* to be two such particles repelling each other at the distance *A B* with a force = 1. continue the line *A B* indefinitely through the equidistant points *c*, *d*, *e*, &c. let the particle *A* be fixed, *B* moveable: let us suppose this power to decrease, 1st, simply, as the distances increase; then, if we suppose the particle B to move successively through c, d, e, &c. this power, at those several distances, will be as follows, viz.

at $c = \frac{1}{2}$, at $d = \frac{1}{3}$, at $e = \frac{1}{4}$, &c. in infinit.

2. If it decrease as the squares increase, it is at } $c = \frac{1}{4}$, at $d = \frac{1}{9}$, at $e = \frac{1}{16}$, &c. in inf.

3. If as the cubes it is at } $c = \frac{1}{8}$, at $d = \frac{1}{27}$, at $e = \frac{1}{64}$, &c. in inf.

4. If as the biquadrates, it is at } $c = \frac{1}{16}$, at $d = \frac{1}{81}$, at $e = \frac{1}{256}$, &c. in inf.

&c. onwards indefinitely.

Now whatever the distance assigned between the two particles may be, and whatever may be the index of the power which expresses the ratio of the decrease of their repulsive force, this force will in every case be expressible by a fraction whose numerator is 1, and its denominator equal to the given distance, involved according to the index of the given power, as is evident from inspection of the foregoing fractions as they stand. It can never, therefore, become equal to nothing, until the denominator of the fraction becomes infinite, which never can be at any assignable distance, however great; therefore, the extent of this mutual repulsion is indefinite. Q. E. D.

In mathematical reasoning, the smallest quantities are not to be disregarded, unless supposed smaller than any assignable, as in fluxions, &c.; for, as all the huge masses of the solar system, are composed of particles of matter inconceivably small, so their mechanical effects upon each other are proportional to the numbers of such component particles they respectively contain; and though the mutual effects of two single particles, at any given distance, might be indefinitely small, yet we may easily conceive, that, when indefinite numbers of such particles are consolidated into one mass, and exert their influence from a common centre, that *that influence* may be as extensive as the solar system, and perhaps as the material universe. Thus the sun, by the united attractive force of his constituent particles, regulates the motions of the Comets, even at their aphelia, where their distances from him confound the human imagination; amounting in some of them to many thousands of millions of miles; yet, at those amazing distances from the sun, they are by his influence retained in their proper orbits, without any deviation, till at length they are brought back to him again, many of them after excursions of some hundreds, and possibly some of them after thousands of years; in effecting which every particle of matter in the sun, however small, bears a part.

On the other hand, the atmospheres of the heavenly bodies consist of particles mutually repellent; not consolidated indeed, as that would be incompatible with the nature of the fluid composed of them, but each, in consequence of the mutual attraction between its constituent particles and the globe it surrounds, condensed into a fluid mass.

In this case also, though the mutual repellency between two single particles might at a given distance be indefinitely small, yet the influence of two such masses upon each other, when thus condensed, may be as extensive as in the former case of attraction. The united repulsive force of the particles in each, would in like manner exert itself as from their common centre.

Let us, for illustration of the subject, suppose this repellent power between the particles A and B, Fig. 1, to decrease as the squares of the distances increase, then at a distance equal to 100,000,000 A B, or, in other words, suppose the particles A and B removed *one hundred millions* of times further asunder than represented in the figure, the repulsive force would then be equal to $\frac{1}{10000000000000000}$, or to one *ten-thousand-million-millionth* part of what it is at the simple distance A B ; which, though small indeed, is yet something, for the same distance remaining, viz. 100,000,000 A B, if *ten thousands of millions of millions* of such particles of equal bulk and repellency were condensed round the point A as a centre, then the repulsive force between the mass at A and the particle B would be equal to that between the two single particles A and B, at the distance A B ; once more, suppose the same distance, viz. 100,000,000 A B to remain, and the particle B to have the same number of repellent particles condensed round it, as we have already supposed, to be condensed round A ; then the repulsive power subsisting between the two masses would be *ten thousands of millions of millions* of times greater than between the two particles *A* and *B*, at the distance *A B*.

We have seen that air consists of particles thus repellent; nor can we discover any bounds to that repellency by any experiments we can make; and if to other experiments we add Sir *Isaac Newton's* reasoning from some of his own, we must conclude them indefinitely so, and consequently that their repulsive force decreases regularly according to some certain ratio of the increase of their distances, viz. either as the *distances simply*, or as their *squares*, *cubes*, or some other *powers* thereof.

It seems most agreeable to mathematical reasoning, to suppose, that all powers, whether attractive or repellent, which act in right lines, to, or from the centres of the attracting or repelling bodies, are proportioned to the inverse ratio of the *squares* of the distances of their centres. For, if we consider these powers as represented by lines, or rays, converging from every point of the visible concave of the Heavens to a given point as a centre in case of attraction, and diverging equally from said centre in case of repulsion; and suppose a corpuscle of matter to be placed in any part of that space, the number of such rays, intercepted by, and falling upon said corpuscle, whether they were converging or diverging, would be *in that ratio*, *viz.* inversely as the *squares* of the distances of said corpuscle from such central point. The truth of this assertion is capable of the most simple mathematical demonstration; which may be here omitted, as it has been already sufficiently demonstrated by others: Upon it indeed depends the truth of Sir *I. Newton's* position, viz. that "the density of the sun's "rays is reciprocally as the *squares* of the distances "from the sun;" from whence he deduces the proportions of light and heat, enjoyed by the several planets of the system.

If we conceive such supposed rays to move with a uniform velocity, and to be attended with any momentum whatever, whereby, when converging, they impel the corpuscle to, or repel it, when diverging, from said central point; as the whole momentum would be proportional to the number of the intercepted rays, the tendency of the corpuscle to, or from the centre, that is, its attraction or repulsion would also be in the aforesaid ratio. That the attraction of gravitation is regulated by this law, astronomical observations sufficiently demonstrate.

But Sir *I. Newton* concludes from experiments, to which all theoretic opinions must ever give way, that the mutual repellency between the particles of air is reciprocally as their distances only, or "nearly so."*

If this be the case, the physical effects of two particles, and consequently of two fluid masses composed of such particles, upon each other, must be yet vastly greater than if it were reciprocally as the *squares* of the distances, as we before supposed, as will evidently appear upon inspection of the following scheme

* Newt. Princip. Book II. Prop. XXIII.

in which the *first* series represents the distances, increasing in arithmetical progression; the *second*, the repellent force, decreasing as the distances increase only; the *third*, the same force considered as decreasing according to the increase of the *squares* of the distances; thus: *A B*

Distances — —	⊙	1	2	3	4	5	6	7	8	&c.
Inverse ratio of dist.	⊙	1	$\frac{1}{2}$	$\frac{1}{3}$	$\frac{1}{4}$	$\frac{1}{5}$	$\frac{1}{6}$	$\frac{1}{7}$	$\frac{1}{8}$	
--of the squa. of dist.	⊙	1	$\frac{1}{4}$	$\frac{1}{9}$	$\frac{1}{16}$	$\frac{1}{25}$	$\frac{1}{36}$	$\frac{1}{49}$	$\frac{1}{64}$	

Here it is evident that at the distance 3 *A B*, if the repellency decreased only as the distances increase, that that force would be equal to $\frac{1}{3}$; but if it decreased as the *squares* of the distances increase, it would at the same distance be equal only to $\frac{1}{9}$; at the distance 5 *A B*, in the former case, it would be $\frac{1}{5}$, in the latter $\frac{1}{25}$; if at the distance 8 *A B*, in the former it would be $\frac{1}{8}$, in the latter $\frac{1}{64}$, &c. But 3 is the square-root of 9 or $\frac{1}{3}$ of $\frac{1}{9}$, $\frac{1}{5}$ of $\frac{1}{25}$, and $\frac{1}{8}$ of $\frac{1}{64}$, &c.

It therefore follows, that if this repellent force does actually decrease simply as the distances increase, the quantity of it at any given distance is greater, in the direct ratio of that distance, than if it decreased in the ratio of the *squares* of the distances; consequently, the sensible effects of two such fluid masses, condensed, as we have already supposed, round the particles *A* and *B*, would be proportionably more extensive.

Now, what are the atmospheres of the sun, planets and Comets, but vast collections of these repellent particles of air, condensed round their respective globes, by the mutual gravitation subsisting between them, in like manner as we have already supposed them to be condensed round the corpuscles *A* and *B* (Fig. 1.)? But if, according to Sir *I. Newton*, so small a quantity as a cubic inch of our air, if left to itself at the height only of one semidiameter of the earth, might exert this force, so as to fill the whole sphere of Saturn's orbit; it demonstrably follows, that the atmospheres aforesaid, which consist of huge masses of the same fluid, may extend their influences as far at least; and though the condensation of each round its own globe, by virtue of their mutual gravitation, would prevent the scattering of its component particles, and confounding itself with the atmospheres of the neighbouring planets (as would undoubtedly be the case, however great their distances might be, did the cause of that condensation cease) yet it is by no means impossible, nor yet improbable, that under some circumstances, the physical effects of two such atmospheres upon each other may become very apparent: For if we suppose two equal planets with their atmospheres (as *A* and *B* Fig. 2) to pass near to each other, these atmospheres being fluid, and that in the highest conceivable degree of fluidity, would give way to the least degree of external force, and in consequence of their mutual repulsion would recede from each other; but the attractions of their respective globes would prevent their leaving them wholly, while each would so far retire, as to be depressed in the parts next the other, and to swell out in the opposite parts, changing their spherical figures to two oblong spheroids as at *C* and *D* (Fig. 2.) But this is said upon the supposition that both the globes and their atmospheres are equal, each to the other respectively. Whereas, if we suppose the body *A* to be an immense globe like the sun, having an atmosphere proportionably large,* and consequently containing many thousands, and perhaps some millions of times the quantity of this repellent fluid contained in the atmosphere of *B* ; which we may now consider as a Comet, of equal magnitude with the earth, but surrounded, like other planets of the same species, with an atmosphere of great extent, when compared with the magnitude of the globe itself; and if we suppose also the visible effects of the mutual repellency of these atmospheres to be reciprocally as the quantities of the repellent fluid contained in them, the atmosphere of the Comet might

* The solar atmosphere is dense enough at the height of seven or eight thousand miles, or 1-137th part of the sun's diameter above his surface, to sustain those huge clouds of smoke which appear to us like spots upon his disc. See Mr. Professor *Winthrop's Cogitata de Cometis,* page 25. If therefore the atmosphere of the sun consists of air, as we have endeavoured to prove it does, and the solar clouds and vapors are similar to our own, and, like them, require a certain density of air to sustain them in equilibrio, it follows, that the density of the air in the sun's atmosphere is as great at the height of 7000 miles above his surface, as that of our own air, at the height of but 3 or 4 miles above the surface of the earth ; a height which our clouds, probably, never exceed. How vast then must be the extent of the sun's whole atmosphere !

be prodigiously lengthened when in the neighbourhood of the sun, and repelled to great distances behind the nucleus, while at the same time, the natural spherical form of the sun's atmosphere would not be sensibly disturbed by that of the Comet. This reasoning may be illustrated by considering the effects of the contrary principle of mutual attraction or gravitation subsisting between the globes themselves, which effects are subjects, both of mathematical computation, and of astronomical observation : For it is very certain that Comets perform their revolutions round the sun, in consequence of this mutual gravitation, in orbits very eccentric, and nearly parabolical; whereas it is probable, that the joint efforts of all the Comets which ever appeared, would scarcely disturb the repose of the sun in the centre of the system.

A comet, in its descent through the planetary orbs, approaches the sun with an accelerating velocity, until it arrives at its perihelion; entering deeper and deeper within the spheres, both of the repulsion of the sun's atmosphere, and of the activity of his rays; in consequence whereof the cometic atmosphere is continually rarefying during this descent, both from the expansion it undergoes, by means of that repulsion, and from the increasing heat, which it acquires, as it approaches the sun, which heat, as already observed, contributes greatly to the repellency of the particles of the ærial fluid. By the concurrence of these causes, if admitted, a tail must necessarily be formed, the length of which would depend, partly upon the quantity of air contained in the cometic atmosphere, and partly upon its proximity to that of the sun, and consequently would increase until the Comet arrived at its perihelion, or rather, from the continuance of the causes, until a few days after, which is most agreeable to observation. When a Comet is at this stage of its revolution, if it pass near the sun, the tail usually extends from its head through vast regions of space, exhibiting a curious spectacle to distant worlds.

If a cometic atmosphere consisted of an *unelastic* fluid, and were thus repelled by the atmosphere of the sun, it would put on the form of a very oblong spheroid, both ends of which would be terminated by a regular curvilinear surface as at *A* and *a* (Fig. 3); but as it is an elastic fluid, whose constituent particles are, amongst themselves, mutually repellent, as soon as ever the attraction of nucleus, which before condensed them spherically round itself, is diminished in *any* part of that atmosphere, by this opposite repulsion, the particles in *that* part become more and more at liberty to exert their own inherent repellency, which they would at length do *quaqua versum*, were it not that the repellent power of the sun's whole atmosphere, so far predominates over their own mutual repellency, as constantly to keep them in a direction nearly opposite to the sun's centre; but as this is not sufficient totally to prevent a lateral dilatation, the tail grows broader and broader, as it extends from the nucleus, while the longitudinal expansion is rather increased than impeded thereby, until the whole train, in a fair view of it, wears nearly the form of a parabolic curve; the several parts of which are less and less distinct, as they are further distant from the head, until at length, spectators shall, at the same time, differ ten or twenty degrees in their estimation of its apparent length, according to the different acuteness of their sight.* (See Fig. 4. *B b.*)

After the perihelion, as the Comet recedes from the sun, the mutual repulsion of the two atmospheres gradually decreases, while the mutual gravitation of the Comet and its own atmosphere proportionably gets the better of it, until at length the exiled atoms are drawn home, and that perhaps without the loss of a single one; unless the tail should happen to sweep the sphere of some planet in its way; in which case, if the atmosphere of the planet were large, the mutual repellency of the two would rather occasion a bifurcation of the cometic atmosphere than a union or confusion of them; but were that of the planet very small, and did we suppose that in consequence thereof, that of the Comet might leave a small portion of its tail behind; still no detriment to us could reasonably be expected or feared, upon that account, considering the amazing rarity of the Comet's tail. The cometic atmosphere being gradually re-condensed

* Sir *I. Newton* in his Princip. says, "the Comet of 1680, "in the month of December, emitted a notable tail, extending "to the length of 40°, 50°, 60°, *or* 70° and upwards:" The disjunctive (*or*) intimates an uncertainty, of at least 30 degrees, in its apparent length.

round its nucleus as before, would provide it with a suitable garment for winter quarters in the remote parts of its orbit; agreeable to the ingenious hypothesis of Dr. *Williamson.*

The thickness of a Comet's tail, or the diameter of a section made perpendicularly through it, is amazingly great towards its extremity; the apparent breadth of the tail of the Comet of 1680, where its distance from the earth was equal to the distance of the earth from the sun, was equal to above three apparent diameters of the sun;* consequently the real thickness of that part of the tail was about three millions of miles, or between three and four hundred diameters of the earth, yet, says Sir *I. Newton*, "the smallest "stars were visible through it without any diminution "of their lustre." How inconceivably rare then must it have been! Perhaps for some thousands, not to say millions of miles, reckoned from its extremity towards its head, it might not have contained more air than a well blown bladder does with us: And that this is not only possible, but even probable, appears from Sir *I. Newton's* computation of the expansion which a cubic inch of our air is capable of, already repeatedly referred to.

So much for the third general proposition, which the reader will receive or reject, according to the weight of the evidence offered in support of it. It

* The author remembers to have met with this observation somewhere, but cannot at present recollect where. But it was not far from the truth, if applied to the Comet of 1769.

is however hoped that candour will be exercised, and that the whole will not be exploded, merely, for want of accuracy in the method, or of perspicuity in handling a subject so difficult of access.

A short digression here may not be amiss, in order to prevent the uncomfortable impressions, which the appearance of a Comet is apt to make upon the minds of some, and which were greatly increased during the appearance of the Comet of 1769, by an injudicious publication in one of the southern newspapers, wherein it was insinuated, that if that Comet should pass between the earth and the sun, the earth would pass through the tail of the Comet; the consequence of which, the writer supposed, might be fatal even to the world itself. But from the foregoing observations it is evident, that such apprehensions were groundless. The ingenious and learned Mr. *Whiston* has indeed endeavoured to prove, in order to support his *Theory*, that a Comet passing near the earth in its descent towards the sun, occasioned the universal deluge, by leaving behind it a sufficient quantity of vapors from its atmosphere and tail, (in which he supposed the earth to be enveloped,) when condensed into rain, to drown the world. He further supposed that a Comet, in its ascent from the sun, might be sufficiently heated to cause a general conflagration, should it find the earth in the same situation. In consequence of which the fears of many are usually alarmed, at the appearance of a Comet, by the apprehension of some grand catastrophe. But if the tails of Comets are so extremely rare, as we find they must necessarily be, and as every one must be convinced they are, who ever saw the stars shining through them ; how can we conceive that the earth in passing through one of them, could carry off *oceans* sufficient to submerge " *all the* " *high hills under the whole heaven?*" to effect which, many of *our* oceans would, doubtless, be necessary. On the contrary, it seems probable, from the foregoing considerations, that the tails of all the Comets which ever appeared, could not, jointly, furnish water sufficient for one *ocean* only.—If so, the near approach of a Comet must be found utterly insufficient to account for the superior waters of the deluge, or the forty days rain mentioned by *Moses* ; whatever disorders might otherwise be occasioned in both globes, by their mutual gravitation, in such vicinity. And had the earth passed directly through the midst of the tail of the Comet of 1769, or of any other, it is not in the least probable, unless the Comet had come near enough to injure us upon other accounts, that the earth could have carried off with it, or that the Comet would have imparted to us, vapors sufficient, even for a common thunder shower. But this is submitted to the reader ; who, perhaps, upon the perusal of the second part of this essay, may be of opinion, that a Comet, in its ascent from the sun, is no more calculated to set the world on fire, than to drown it in its descent. But to return to our subject.

Here a material objection may naturally arise, viz. why should the Comets appear with tails, and those, generally, of enormous lengths, while the planets, which have atmospheres as well as the Comets, are always seen without them, even when at equal distances from the sun?

To this it may be answered; that the atmospheres of the planets are so small, in proportion to the globes they surround, compared with those of Comets, that whatever may be the cause of the tails of the latter; if the same cause act upon their several atmospheres, proportionably to the spaces they respectively occupy, the tails of Comets may appear of astonishing lengths, while those of the planets shall be totally insensible. In other words; the planets in similar situations shall have no tails at all.

The earth, as has been repeatedly observed, is a planet, with which, as it is the place of our abode, we are well acquainted: The height of its atmosphere is generally computed at about fifty miles; beyond which, its density is not sufficient to reflect the rays of the sun in the crepusculum or twilight: The diameter of the earth is about 8000 miles, the diameter then of the earth and atmosphere together is about 8100 miles; from whence it appears by computation, that the space occupied by the atmosphere alone is to the space occupied by the earth alone, as 1 to 26 nearly.

The diameter of the atmosphere of a Comet, as before observed, is, at a medium, equal to ten times the diameter of its nucleus; and, spheres being as the cubes of their diameters, the magnitude of a Comet and its atmosphere together is equal to one thousand times the magnitude of the Comet alone; consequently, the space occupied by the atmosphere, is to the space occupied by the nucleus as 999 to 1.

Let us suppose a Comet of equal bigness with the earth, having an atmosphere as above described, to be so situated, as that the sun, the earth and the Comet, may be in the angles of an equilateral triangle: Let us suppose also the visible effect of the repelling power of the sun's atmosphere upon those of the earth and the Comet, to be in proportion to the spaces they respectively occupy: The magnitudes of these atmospheres being one to the other as 999 to $\frac{1}{26}$, that is as 25974 to 1; when a spectator upon the earth might see the tail of the Comet extend through an arch in the heavens of 60°; had the atmosphere of the earth a tail, arising from the same cause, in proportion to the space it occupied, to a spectator upon the Comet it would subtend an angle of no more than 0° 0′ 8″ 81‴ or 60° divided by 25974, an angle which the best instruments could never discover in an object so dubiously defined: In other words, when the Comet would have a tail 60° in length, a planet at the same distance from the sun would have none at all.

The atmospheres of the inferior planets are probably less in proportion, and those of the superior, larger than that of the earth. But this subject may more properly be introduced in the second part of this Essay.

The principal of repulsion by which we have endeavoured to account for the tails of Comets, and their opposition to the sun, may receive further confirmation by considering some of the phænomena which the atmosphere of a Comet would exhibit in the neighbourhood of the sun, were the sun divested of his atmosphere, or were his atmosphere deprived of its repellent principle: We shall therefore endeavour to prove the following proposition, *viz.*

Were the sun without an atmosphere, or some other appendage in its nature repellent to the atmospheres of Comets, and the æthereal spaces void of resistance; instead of *one* tail, and that always turned from the sun, every Comet would have *two*; the direction of one being *towards*, the other *from* the sun, of which the former would be the most considerable, and both would increase as the Comet approached the sun, from the increasing gravitation towards him.

For though a Comet's atmosphere in its natural state surrounds the nucleus in a spherical form, (a form that every fluid, the several parts of which tend to a common centre of gravity must put on) yet if we suppose this atmosphere to be affected by its gravitation towards the sun, and to consist of an unelastic fluid, like water; those parts of this fluid which were nearest to, and most remote from the sun, would have their gravitation towards the centre of the Comet lessened by the sun's attraction, and thereby, from a spherical form the whole would be changed to an oblong spheroid. This is in fact the case with our ocean, which is changed from a sphere to a spheroid by the gravitation of the moon; the axis of which spheroid, revolving round the axis of the earth in consequence of the diurnal motion, causes the flux and reflux of our sea. But the atmosphere of a Comet is indefinitely elastic, and thence capable of an unlimited expansion; therefore, in proportion as it is in any part elevated above the superficies of the sphere it occupies when in its natural quiescent state, such parts are proportionably at liberty to expand themselves, by virtue of the mutual repulsion of their component particles, which are now in great measure freed from that constraint which before condensed them;* which would change both ends of the spheroidal figure, to forms similar to the tails which commonly attend the Comets, being broader as they become rarer towards their extremities, on one side and the other: But the tail next the sun would be the most considerable, the effects of his attraction on that side being greatest; and, should the Comet approach near enough to the sun, a continued aerial stream would be formed from one globe to the other, whereby the sun, by his superior attractive power, would by degrees rob the Comet of its atmosphere, condensing the same round his own globe, without leaving the Comet a sufficiency for the purposes of life and vegetation in its solitary retreat without the planetary spheres. But as the sun has an atmosphere, repellent to the atmospheres of the other heavenly bodies, these inconveniences are thereby prevented, and every globe of

* See page 98.

the system retains its own, unimpaired, through every stage of its revolution.

That the projection of the tail of a Comet from its nucleus, and its perpetual opposition to the sun, do arise from the mutual repellency of the atmospheres of sun and Comet, as we have endeavoured to prove in the foregoing pages; may be confirmed and illustrated, if not demonstrated by electrical experiments.

The electric fluid is an element, as distinct from all others which we are acquainted with, as air is from water; and if there be any such thing existing in nature, as pure elementary fire, this claims that character, in preference to all others. For fire, in its common form, is so far from being a pure element, of itself, that the presence of air is necessary to its very being. Whereas the electric fire, in many experiments, acts with greater freedom *in vacuo*, than in the open air. But, different as this wonderful substance is from all others, we find, that some of its properties greatly resemble those of air, already treated of: And, if the following propositions, which are introduced to prove that resemblance, can be confirmed by experiments; and it be allowed, that similar causes, naturally, produce similar effects; it is presumed, that the solutions of the cometic phænomena, offered in this essay, when compared with those experiments, will be found not inadequate to the phænomena.

Prop. 1. There is a mutual attraction, subsisting betwixt the electric fluid and common matter; in consequence of which, the former is capable of, and liable to a condensation round the latter; in the same manner as air, by common gravitation, is condensed round the heavenly bodies, in the form of atmospheres.

The truth of this proposition has been abundantly proved by Dr. *Franklin*, and other writers upon this subject: Indeed, the success of all our electrical experiments depends upon this property: We may add further, that all the phænomena which have ever been observed, in which that element is concerned, from the attraction of small hairs, dust, &c. in consequence of the attrition of amber, to the most severe blaze and irresistible force of lightning; depend in a great measure, upon the same property.

Prop. 2. Air, as we have seen, is a fluid, the particles of which mutually repel each other: So, also, is the electric element.

The truth of this proposition is demonstrated by the following

EXPERIMENT I.

Suspend a plate of metal, by wire, from the prime-conductor generally used in these experiments, and electrify it. On another plate, placed under the former, at the distance of three or four inches, put a small quantity of dry sand, meal, bran, flour, or even the most impalpable powder; the particles upon the lower plate, being attracted by, and themselves attracting the electric atmosphere, condensed round the under surface of the upper plate, a beautiful shower will ensue: These particulars will ascend to the upper plate; each, by virtue of the aforesaid attraction, will receive, and condense round itself, in the form of an atmosphere, a quantity of this fluid proportional to its capacity; be immediately repelled from it, and descend towards the lower plate: But these corpuscles descend, diverging from each other, many of them falling wide of the plate, upon the table beneath, to return no more: Which divergency, not only indicates, but is the necessary consequence of, the mutual repellency of the electric atmospheres, now condensed round them. Those that recover the lower plate, having discharged their fire, re-ascend together with those that were left behind at first; with them receive a new charge, and return diverging, as before. This operation continues, until most of the particles are scattered on the table below, few being left between the two plates. Now, as the quantity of the fluid condensed round each corpuscle is, probably, proportional to the superfices of the corpuscle;* and as this experiment will succeed with an impalpable powder, if perfectly dry, we may conclude that the smallest conceivable portions of the electric matter, when once severed, are mutually repellent; from whence we

* See Doctor *Franklin's* printed letters, page 55. § 15. wherein he asserts, that "The form of the electrical atmosphere is "that of the body it surrounds."—This he proves by experiments, and from this principle has given a probable solution of the operation of points, at a distance from the electrified bodies.

may infer the repellency of its constituent particles themselves.

This property is also largely treated of by Doctor *Franklin*,* and is as necessary to most electrical experiments, as the former is to all; and, doubtless, contributes one half to the amazing rapidity of lightning, to which nothing, short of that of the rays of light, can be compared.

Prop. 3. When two small spherical bodies have electrical atmospheres, condensed round them; those atmospheres are mutually repellent: As we have endeavoured to prove, from the known mutual repellency of the particles of air, that the atmospheres of the heavenly bodies are, amongst themselves.

This proposition naturally results from the last, and is, in some measure, involved in it; but, as the experiments now to be produced in support of it, may shew us in what manner the electric atmospheres act upon, and affect each other, it deserves a more particular consideration. For, as these atmospheres are

* See *Franklin's* letters, p. 37. § 5. where he says, "Every "particle of matter electrified, is repelled by every other par- "ticle, equally electrified. Thus the stream of a fountain, "naturally dense and continual, when electrified, will separate "and spread in the form of a brush, every drop endeavouring "to recede from every other drop. But on taking out the elec- "trical fire, they close again." To which may be added, that, if a small tin cup, filled with water, having a spout just big enough to let out the water by distinct drops, be electrified, the water will issue from the mouth of the spout in a diverging mist, so long as the cup remains charged, but as soon as discharged again, will fall in distinct drops as before.

invisible, in themselves, and are discoverable, only by their effects, it is necessary to charge them with some substances which reflect the rays of light, in order to render them proper subjects of observation.—But the dust, powders, &c. used in the preceding experiment will not answer that purpose, as they fly off, instantly, upon their receiving, and condensing round themselves a certain portion of the fluid: Instead of which, if fine limber threads are run through the balls, in various directions, and their ends cut off at equal lengths, these threads, as they cannot escape, shew, by their several directions, the tendencies of the electric atmospheres of the bodies they adhere to.

This being premised, we proceed to the following

EXPERIMENT II.

Let a pellet of cork or pith, thus prepared, be suspended, and electrified; the threads will diverge, equally, every way, from its centre as at A Fig. 6. the electric atmosphere being equally condensed, upon overy part of it, and equirepellent from its centre outward. But if two such balls be suspended and electrified, and caused to approach each other, the threads of each, which happen to be next to the other, instead of standing out every way from the centre, as before, will be incurvated towards the line of opposition, as at B and C; whereby the reciprocal repulsion of their atmospheres is rendered visible, as the directions of the threads shew the tendencies of those atmospheres respectively; from which it appears, that they recede from each other, as far as the mutual attraction subsisting between each atmosphere and its own ball, (which at first occasioned a condensation of the former round the latter,) will permit. But that the atmospheres do not wholly fly off, in consequence of this repulsion, is evident, as the threads continue in the same directions, until one, or both be discharged.

Quere. Does not this experiment abundantly confirm and illustrate the reasoning in page 95, relative to the passage of two planets, or comets, attended with large ærial atmospheres, by each other; whose mutual effects are represented at C and D, Fig. 3?

We shall adduce one experiment more, before we close this subject, which may prove as entertaining to him who will be at the trouble of making it, as it is demonstrative of the principle under consideration.

EXPERIMENT III.

Provide a wooden sphere, of four or five inches in diameter (call it A;) let it be gilt, as the metal will better condense the electric fluid upon its surface; also a small pellet, of cork, or pith of elder (which call B,) strung, as in the last experiment, with a few threads, of three or four inches in length: Suppose A to represent the sun, B, a comet; fix A on the wire of an electric bottle, and suspend B by a silken thread from a point, directly over the centre of A, so as that, when neither of them is electrified, B may rest against A, a little below the level of its centre; and charge both ball and pellet. The mutual repellency of their electric atmospheres is so great, as that *that* of B is thrown off as far from A, as the mutual attraction between the pellet and its atmosphere will permit; which attraction is at the same time so strong, as that, rather than suffer a separation, the pellet flies off with its atmosphere, to a certain distance from A, where its natural gravitation to the earth is just balanced by the repellent force of the two atmospheres: There B remains at rest, while its atmosphere retires as much farther as possible from A, without quitting it wholly; instead of which it undergoes a longitudinal dilatation, in opposition to the centre of A, as the atmospheres of comets do, with regard to the sun: This is evident from the directions of the threads, which, observed in a side view, bear a near resemblance to the tails of comets. When the pellet is in this situation, blow it gently with a bellows, in a direction perpendicular to the line connecting the centres; this will give it a projectile motion, which will be regulated by its common gravitation; and as the centre of A is directly under the point from which B is suspended, the latter will be carried round the former, as the centre of its motion. Thus will this little comet perform many revolutions round its electric sun, and in every one, and through every part of each, the tail of threads will constantly maintain its opposition to it, as the tails of comets do to the sun in the heavens.

This experiment was very agreeably repeated with an artificial comet, consisting of a small, gilt cork ball, with a tail of leaf-gold, about two inches and an half in length; when, during the whole time of the experiment, in which it performed, at least, twenty revolutions, the tail, as nearly as the eye could judge, was constantly projected in the line of the opposition of the centres of the two balls; the thread, by which the smaller one was suspended, either twisting, or untwisting, the same way, during the whole time. When thus in motion, if we raised the globe, the tail was depressed; when it was lowered, the tail was elevated; maintaining its opposition, in every situation.

But now, from these experiments, some may, perhaps, be inclined to think, that the electric fluid is the sole cause of the phænomena of the tails of Comets: That the sun, as it is the grand source of light and heat, throughout our system, may be the fountain, from which this element, also, is somehow derived to its several globes: That Comets, for wise ends, unknown to us, have a larger share of this fluid than the planets; and that, when they approach the sun's electrical atmosphere, their own are thereby repelled, as in the foregoing experiments; and appear as lucid, diverging beams, like those which, in the dark, we see streaming from electrified points.

This hypothesis might indeed solve the phænomena of the cometic tails, provided the electric atmospheres of bodies, charged with that fluid, were visible in any of our experiments, even when made in the dark: But as that is never the case, unless the fluid be in motion; and as the proof of the existence of such atmospheres, when at rest, depends solely upon their effects upon other substances, the hypothesis cannot be admitted. Were this indeed the *true* and *sole* cause of the phænomena, a planet, near which a Comet might happen to pass, would be in a situation, truly hazardous; for it is evident that the planets (upon that supposition) are not accommodated with such vast electric atmospheres as attend the Comets; consequently, have not the same proportion of that fluid condensed round them, but far short of it:—Therefore, whenever the electric tail of a Comet passed near a planet, it would be attracted by *it*, be drawn aside, from its opposition to the sun, towards *it*, and upon *it* discharge the *surplussage* of its fire, that both might have equal, or proportional shares; which discharge, if we consider the snap of a small spark between two cork pellets, and enlarge the idea, proportionably, to that instantaneous cataract of fire which would necessarily take place between two worlds in similar situations, we may well imagine would give an explosion, which nothing could equal, short of the final voice of an archangel; and, if it were not sufficient to rouse the ashes of the dead, might reduce the living to their primitive dust. But such a catastrophe, we have not the least reason to dread, from the neighbourhood of a Comet, unless we can suppose, that infinite wisdom and goodness would create one world, merely for the destruction of another; as we cannot conceive of any other ends, to which such huge electrical atmospheres could be adapted. Indeed the discharge would be equally fatal to both worlds; as it is certain from electrical experiments, that the effects of a stroke of lightning are the same, whether the flash proceeds from the cloud to the earth, or is descharged from the earth into the cloud, both of which have happened during the same thunder-gust; as appears from observations made by Mr. *Kinnersly* and Doctor *Franklin*,* communicated to the Royal Society. But to put this matter beyond all reasonable doubt, we may further observe, that if the phænomena of Comet's tails arose from the same cause, which renders the electric stream visible, when proceeding from a steel point, these tails would shine by their own light, as the electric fluid does, when in motion; whereas, an apparent obscuration or defect, in one of those tails, has been observed, which evidently arose from the shadow of its nucleus, which occasioned a partial eclipse of the tail, by intercepting the sun's rays:† consequently, the tail, as well as the head, shines with a borrowed light, and both are visible, only by reflecting the rays of the sun.

As the consideration of the properties of the electric element was introduced, merely, to *illustrate* the several propositions, and the conclusions resulting from them, contained in the foregoing pages; it was thought proper to add thus much upon that subject, in order to prevent the framing an hypothesis from those properties, which, instead of removing the fears of the timorous, upon the appearance of a Comet, (which was one design of this essay,) would natu-

* Franklin's letter's, page 116 and 129.

† Hevelii Cometographia Lib. xii. page 898, quoted by Mr. Professor Winthrop in his 2d Lecture on Comets.

rally tend to increase their apprehensions. Whereas, upon the principles we have endeavoured to establish, the tails of Comets appear to be nothing more than air, immensely expanded and rarefied; through which the earth might pass, with the utmost safety to its inhabitants. And, instead of these bodies being heralds, sent fourth to denounce the wrath of heaven, in which light they have been considered by the ignorant and superstitious, of all ages; or the immediate executioners of divine vengeance, as others have apprehended; we shall endeavour to prove, in the following pages, that comets deserve to be considered in a more respectable light; and that their tails, however awful and portentous they have been esteemed by some; may be designed for, and are wisely adapted to, the truly god-like purposes, of rendering habitable a vast variety of worlds; and of affording a *comfortable* subsistence to innumerable species of beings, by which they are, probably, inhabited.

ESSAY ON COMETS.

PART II.

As ancient geographers imagined the polar and equatorial regions, or the frigid and torrid zones of the earth, were uninhabitable, in consequence of the extremes of heat and cold, to which those climates are exposed: so, modern astronomers have passed a similar judgment upon the superior and inferior planets, especially on *Saturn* and *Mercury*; concluding, that our water would always boil upon the latter, and be frozen upon the former; and that merely in consequence of their different distances from the sun.* Whence it has been naturally concluded, that the textures of their various fluids, and of their inhabitants, to whose uses these fluids are adapted, are very different from what they are found to be upon our earth: and, considering the near approaches of most Comets *to*, and the vast elongations of all their orbits *from* the sun, it has been generally supposed, that no material race of beings could subsist under such amazing vicissitudes of heat and cold, as those bodies

* See Newt. princip. Book iii. Prop. viii. Cor. 4.

must, from their different situations, necessarily be exposed to; consequently that they are uninhabited.

But the conclusiveness of this reasoning depends upon the truth of the following proposition; advanced indeed by Sir *Isaac Newton;* but not supported by experiments, which were, with him, the *criterion veritatis*; viz. that, "*The heat of the sun is as the density* "*of his rays, that is reciprocally as the squares of the dis-* "*tances from the sun.*"*

Here, we are again reduced to the disagreeable necessity, of dissenting from the opinion of the greatest GENIUS that ever dignified human reason; which, considering the justly celebrated fame of that illustrious author, may be stigmatized as ignorance or vanity: but it is hoped that the reader will wave that imputation, if he shall judge, upon the whole, that Sir *Isaac* himself would have altered his opinion, upon the evidence which we shall produce in support of the contrary position: we may, however, lay down this as a maxim, that, in the prosecution of any science, the progress of the mind must necessarily be retarded, in proportion to the *implicit* assent we give to the decisions of any man, however great. We shall therefore, without further apology, endeavour to prove that the heat of the sun, as perceived by us, and as discoverable by its effects upon other substances exposed to his rays, does not depend upon the density of those rays *only*, though *they* are necessary to the very existence of that heat; but, *equally* upon the

* Princip. under Prop. xli. Book iii.

concurrent operation of another cause, which we shall presently consider; from whence it will follow, that these causes, wherever they co-exist, whether upon the earth, or upon the heavenly bodies, will naturally produce similar effects.

In the mean time, before we engage in the discussion of planetary heat, as depending upon the several distances of the planets from the sun; it may throw some light upon this subject if we consider the portion of that heat which falls to our own share, and the distribution of it throughout the various climates of the earth.

The surface of the earth has, by geographers, been divided into five zones, viz. one *torrid*, including all the regions between the tropics, upon every part of which the sun shines perpendicularly twice every year: Two *frigid*, which are situated between the polar-circles and the poles, and endure the rigours of perpetual winter, as the former is always basking in a summer sun: And two *temperate*, which experience the vicissitudes of winter and summer, and, in some parts of them, in their extremes; these are situated between the *frigid* and *torrid* zones, in both hemispheres. In the first of these, the seasons are much more uniform than in the others, the days and nights being nearly of equal lengths, the year round; and although the heat may, for a constancy, be greater therein than in any other climate, yet it is not liable to such great and sudden changes as are experienced in the temperate zones; for, during a whole annual revolution of the earth, the difference of the degrees of heat, experienced in the *torrid* zone, as determined by the thermometer, are not so great as those which, sometimes, happen in the *temperate* zones, within the compass of a few hours :* Much more do they fall short of the extremes which are endured in the latter, in the opposite seasons of the year.† But what is above asserted of the *torrid* zone is to be understood only of the

* One morning, in the winter of 1768, the mercury in *Farenheit's* thermometer was 5° below 0°; by 11 o'clock the same day it had risen to 30°, and the next day to above 60° ; the difference being 65° in little more than 24 hours. Again, May 30, 1764, when the general election for the choice of counsellors, for this province, was held at *Concord*, (a town about 20 miles west from *Boston*) the weather was (for the season) extremely hot ; but on the morning of the 1st June following, a severe frost cut off all the Indian corn, beans and other tender annual vegetables, in that and the towns adjacent, for miles round. And on one Sunday morning, in the winter of 1759-60, a transition was made, instantaneously, from severe cold to summer heat ; to the great surprise of every one, and to the no small terror of many. The buildings suddenly smoked to such a degree, that, in some of the worshipping assemblies at *Boston*, the people suspected that the neighbouring houses were on fire ; and there was scarely a person, who did not recoil from the heat, at the church doors, at the close of the service.

† One summer's afternoon in the year 1760, the thermometer, being exposed to the open air, in the shade, the mercury stood at 102°. At another time, viz. in the winter of 1766-67, the sun being an hour high in the morning, it was at 9° below 0°. These were probably, as great extremes as have been observed in this climate, the difference being 111° by the thermometer.

low, inhabited and cultivated countries, the mountainous regions with which those climates abound being excepted, for reasons which will hereafter appear.

The axes of the several planets whose diurnal rotations have been discovered are inclined, more or less, to the planes of their respective orbits; consequently, their superficies are divisible into zones and climates, corresponding with those of the earth: And it is, at least, highly probable, that the various climates of each globe, during its periodical revolution round the sun, experience as great vicissitudes of heat and cold as those of the earth: Nor is it unlikely that, in the equatorial regions of the different planets, there may be at the same time as great varieties in the degrees of heat they respectively enjoy, as there are in the temperate zones of the earth in the different seasons of the year; but supposing all this, the inequalities in the distribution of heat to the several planets and their various climates would vanish, when compared with those extremes which they would necessarily be exposed to, at their several distances from the sun, upon the supposition that the sun's heat were as the density of his rays; for were that really the case, the heat of summer upon *Mercury* would be about seven times as great as upon the earth, and above twice as hot as boiling water with us. On the other hand our summer heat would be above ninety times greater than that of *Saturn*, the difference being more than seven times as great as that between our summer heat and the heat of red hot iron:* For it is undoubtedly certain, that the density of the sun's rays is reciprocally as the squares of the distances from the sun; from whence the above conclusions must necessarily follow, if the heat be proportional to that density.

It is certainly then a question well deserving a philosophical inquiry; whether there be not some medium provided in nature, which, being distributed in different proportions to the several planets, may so attemper the heat of the sun to their respective distances from him, as that the inhabitants of all may be equally happy in the enjoyment of it; and that one globe may receive as much benefit, and be exposed to as little injury, from that heat, as any other throughout the system. This indeed seems to be an object so worthy of the attention and providence of the great PARENT of the universe, that a philosophic mind would naturally embrace such an hypothesis, had it, but, the most slender evidence to support it. This medium, we shall find, is actually provided in the element of air, which is, in various proportions, condensed round, and constitutes the atmospheres of the earth and the heavenly bodies.

As air is an element, to which we, and probably the inhabitants of the other planets, are more indebted than is generally imagined; a short dissertation

* Sir *I. Newton* concludes from experiments that boiling water is three times, and red hot iron about twelve times hotter than our summer heat. Princip. Prop. XLI. Book III.

upon some of the advantages which accrue to us, and probably to them, from its presence, may be acceptable to the reader.

Air is a grand medium in nature, through which an all-bountiful providence conveys to us many of the conveniences, comforts, and delights of life. Upon *air* depends the ascent of vapours, and their condensation into clouds, whence they descend in dews and grateful showers, to refresh and fructify the earth.—Upon *air* we depend for the twilight, which affords us an agreeable gradation of shades from day to night; without which we should instantaneously plunge from the light of the sun to midnight darkness; and again emerge from total darkness to the full lustre of day; which would be insufferable to our organs of sight, upon their present constructure. *Air* is also the vehicle of sounds, whether articulate or inarticulate; consequently without it, we should not only be deprived of the artless melody of the woods, and of the raptures which accompany the masterly execution of musical composition; but, (which is of infinitely greater importance to us) there could be no language, no communication of ideas, but by dumb signs; no liberal arts nor sciences in the world. Therefore if we could subsist without this element, all mankind would be like the unhappy few among us who are said to be born deaf and dumb.

It has already been shewn from experiments, that *air* is necessary both to the support of animal life, and to the subsistance of flame: and how far the very being of fire, in any shape, and even of heat itself, may depend upon it, the reader may judge from the following experiments and observations of Mr. *Boyle*, related in *Shaw's* abridgement of his works.

"Coals," says Mr. *Boyle*, "being put glowing into a "receiver, in three minutes after beginning to pump, "the fire totally disappeared.—Other coals being "suspended, in the open air, at the same time, con-"tinued burning until a great part was reduced to "ashes.* Lighted match was found more difficult "to put out by exhausting the air than kindled "charcoal, nevertheless in about seven minutes the "fire was extinguished, beyond the possibility of re-"covery by re-admitting fresh air." Here we see that air is necessary to the subsistance, not only of flame, but of fire that emits no flame at all. To these we may add an easy experiment, which any person may try at his leisure, without the assistance of a pneumatic engine, viz. A composition may be made of allum and flour, which being well mixed together, reduced to a cinder in a crucible, pulverized, and otherwise prepared by a second heat, in a phial secured from the free communication of the external air, acquires an igneous quality, which, if the phial be kept stopped, it will retain unimpared, even for many years; nor will it shew any appearance of fire more than any other matter confined in the same manner; but if at any time a few grains of it be let out upon any combustible substance in the open air,

* Shaw's Boyle, page 419.

it will by the fresh air be instantly changed into fire, and kindle the substance upon which it falls. This powder is commonly called the black phosphorus. From a small quantity of it the experiment may be repeated with success for years together, provided care be taken, whenever the phial is opened to let out any of the powder, to stop it again immediately, to prevent the too free access of the external *air*. Here we have a substance which has all the qualities of fire inherent in it, and retains them for a long time, and yet can never exhibit them but upon the admission of fresh *air*. But to return to Mr. *Boyle*: in page 603 he concludes from experiments, which he had been making in condensed *air*, that "the consumption of "matter by fire is greater in proportion to the quantity of *air* contained in the (same) receiver; or rather in a still greater proportion," as he found by some subsequent experiments. Therefore, as the consumption of matter by fire, without flame, must be proportional to the intensity of the heat which consumes it, we may conclude from this last observation, that the intensity of the heat in any enkindled substance, is nearly proportional to the density of the surrounding *air*, and depends in a great measure upon it. In page 604 Mr. *Boyle* concludes from other experiments, that "fire is more easily kindled in *air* "much compressed, than in common *air*." Now it is certain that, the more intense the heat, the quicker the same combustibles are kindled by it; thus bodies, exposed to the foci of different burning-glasses, will take fire sooner from some than from others, according as the powers of those glasses to condense the sun's rays in their foci (*cæteris paribus*) are greater, by which condensation the heat is proportionably increased: but as in these experiments, made in condensed *air*, Mr. *Boyle* kindled his fire with the rays of the sun, thus collected in the focus of a burning glass, and found, as above, that the same glass would more easily kindle substances, in compressed *air*, than in common air, it follows, that, the density of the sun's rays remaining the same, the heat with which they were accompanied was increased by increasing the density of the *air*; in like manner as if the density of the *air* had remained the same, and the density of the rays had been increased, by using glasses of stronger powers: to which may be added that Mr. *Boyle* always found it extremely difficult, and sometimes impossible to kindle any substance whatever in an exhausted receiver, either by the rays of the sun, or even by red-hot iron in contact with gun-powder itself. The conclusion is obvious to every capacity.

Having thus exhibited to the reader an imperfect sketch of the principal uses to which our air is subservient; wherein among other things, we have seen the necessity of its presence and co-operation in the production of heat by the rays of the sun, in common experiments: we shall now in further prosecution of the subject, proceed to prove that the heat of the sun, as enjoyed by the inhabitants of the earth in general, depends, not only upon the density of the sun's rays, but, equally, upon the density of the surrounding atmosphere. This we shall prove from the testimonies of travellers of the most undoubted reputations who crossed the seas, and undertook the most dangerous and fatiguing journeys which, perhaps, have ever been performed by man, with no other view than to promote the cause of science; particularly *Don George Juan* and *Don Antonio de Ulloa*, and their attendants who were sent by the Courts of *France* and *Spain* to *South-America*, to measure a degree of the meridian under the Equator: In the execution of which commission, they were obliged to take their stations, and make their observations upon some of the highest mountains upon the earth, viz. the *Andes* in the neighbourhood of *Quito*, under the Equinoctial.

It is well known that the tops of high mountains are at all seasons very cold, and are, for the most part, covered with snow the year round. But those above-mentioned, exhibit a scene truly curious; for from their summits to the plains below, inclusively, may be found at the same time, all the varieties of heat and cold, which are to be met with in every climate of the earth, at all seasons of the year.*

One observation made by *Don de Ulloa* upon the spot, is very remarkable, and much to the present point: He says, "the region of continual congela-
"tion began upon the several mountains at the same
"height above the level of the sea, as determined by
"*equal heights of the mercury in the barometer.*" But Sir *Isaac Newton* asserts, and deduces the certainty of it from "actual experiments," that "as to our own

* See *Ulloa's* voyage to *South-America*, Book VI. Ch. VII.

"air, *the denisty of it*" (i. e. at any height) "*is* as the "weight of the whole incumbent air, that is, (says "he) *as the height of the mercury in the barometer.*"* It therefore follows, that the region of "continual con-"gelation," or perpetual frost commenced upon all those mountains, where the air was of the same density. Above that *certain* height, the density of the air lessened, and the cold increased accordingly in severity, till the tops of the mountains presented all the horrors of winter, which are to be found in the polar regions. Whereas below *that* height, as the density of the air increased, from the increase of the incumbent pressure, the heat of the sun also increased; till the inhabitants of the plains below suffered all the inconvencies of the torrid zone.

Now, the density of the sun's rays being the same in the several cases, and the tops of the mountains being above the common region of the clouds, and consequently enjoying the presence of the sun much more than the plains below; it follows, that although the rays of the sun may be the *sine qua non*, without which the inhabitants of the earth would enjoy no heat at all, yet, the degree or *quantum* of their heat depends upon the density and co-operation of the aerial medium through which those rays are transmitted to them.

As the proportionality of the sun's heat to the density of his rays, is a point, upon which, as proved or disproved, many curious questions in natural philo-

* See Princip. Book II. Prop. XXII. Schol.

sophy may turn, every argument which tends to determine that point will doubtless be acceptable to the reader; and if he should be already satisfied in his own mind, from the foregoing observations, that the heat of the sun is *not* as the density of his rays simply, yet it is hoped that he will patiently attend to one argument more, which is drawn from Sir *Isaac Newton's* own principles, and naturally results from his computation of the amazing, inconceivable degree of heat, which must have been acquired by the Comet of 1680, at its perihelion, upon that supposition; which, though it has never been controverted, but generally allowed to be just, and quoted accordingly, must, if true, have occasioned the exhibition of some phænomena, which could not have escaped the notice of the many curious astronomers of that day. According to this great author's calculation, this Comet, by its near approach to the sun at its perihelion, "acquired a degree of heat *two thousand times* greater than the heat of red-hot iron;"* but from previous experiments he concludes, that the heat of red-hot iron is but *twelve* times greater than that which dry earth acquires when exposed to the summer's sun: With what an amazing lustre then must the Comet have glowed, merely from the heat it acquired during its proximity to the sun! Therefore at its first appearance after the perihelion, it must have shone, not with a borrowed or reflected light, as it did before it arrived at that stage, but by its own newly acquired lustre, far exceeding (perhaps) the brightest star in

* Princip. Book III. under Prop. XLI.

the heavens; for if iron heated but *twelve* times more than dry earth exposed to a summer's sun, becomes *red-hot*, and from that heat emits a splendor, independent of the sun's rays, we may defy the human imagination to conceive of that splendor, when yet increased *two thousand* fold, and exhibited by a globe of equal dimensions with the earth. Furthermore, Sir *Isaac* computes that a globe of red-hot iron equal to the earth, or the Comet, supposed of equal bigness, would scarcely cool in *fifty thousand years;* therefore the Comet, being *two thousand* times hotter, if it were a globe of iron, would require 50,000 multiplied by 2,000, or *one hundred millions* of years to cool in. But if we suppose the Comet to cool *a hundred* times faster than an iron globe of the same magnitude, equally heated; it could not lose all its heat under *a million* years;* nay, at the end of *five hundred thousand* years it would still be *a thousand* times hotter, and consequently brighter than red-hot iron. But as the period of this Comet is supposed to be short of *six hundred* years, [several appearances of Comets in past ages being supposed to be different visits from the same Comet, after intervals of *five hundred and seventy five* years;] if at every perihelion it acquired a degree of heat which it could not lose

* This is the duration of heat generally assigned to this Comet, after its perihelion. But why a globe of earth should cool an hundred times faster than a globe of iron, as here supposed, no where appears, nor should the supposition be admitted, unless we suppose at the same time, that a globe of iron is one hundred times denser than a planetary globe; if then.

under *a million* years, and had short of *six hundred* years to discharge itself of the heat acquired at each revolution, how astonishing upon these principles must be the accumulations of its heat during those several revolutions! so great! that one would imagine, that for ages after its perihelion it would be visible merely from its own lustre; and that when, from its distance, its diameter would become insensible, it would still be seen as a lucid point, twinkling among the stars: Yet so far was this from being the case, that in *three months* from its perihelion, viz. from 8th *December* to 9th *March* it totally disappeared, though the earth was in a situation to view it for a considerable time after: Sir *Isaac Newton* says "on the 9th and 10th of "*February* to the naked eye the head appeared no "more."

This Comet, at least its tail, was discovered by Mr. *Flamstead* two days after its perihelion, viz. on the 10th *December*; from which time till its total disappearance, it was constantly observed by astronomers; but none of their observations take notice of any extraordinary brightness it exhibited, more than is usual in the appearance of other Comets. Sir *Isaac* indeed observes, that "in the month of *December*, just after "it had been heated by the sun, it did emit a much "longer tail, and *more splendid* than in the month of "*November* before, when it had not yet arrived at its "perihelion." But this he asserts of the tail only, for soon after he adds, "the head of this Comet at "equal distances from the sun and from the earth, "appeared darker *after* its perihelion than it did *be-*

"*fore* :" It is true he accounts for it by supposing the "nucleus to be environed by a denser and blacker "smoke than before." But this is difficult to reconcile with what he says a page or two back, when speaking of the same Comet, viz. " by so fierce a heat, " vapors and exhalations, and every volatile matter " must have been immediately consumed and dissi- " pated."* May we not add, and the whole solid mass calcined or vitrified? Therefore, if that dulness in its appearance, after the perihelion, was owing to clouds and vapors, it is evident, from that great author's own reasoning, that the Comet could not have been exposed to so great an intensity of heat, in that vicinity to the sun; since all such heterogeneous exhalations must have been consumed and dissipated thereby, as fast as they arose from the head; if indeed any volatile or evaporable matter, or any degree of moisture whatever could have remained in the head after such

* If at the perihelion distance of this Comet from the sun, viz. about 160,000 miles, or 1-6th of the sun's diameter above his surface (according to Sir *I. Newton*,) the sun's heat is so fierce, as that " all kinds of vapors and exhalations must be im- " mediately consumed and dissipated thereby," how is it possible for those clouds, (for such they undoubtedly are, see page 84) which appear, more or less, every day, like spots upon the sun's disc, and float in his atmosphere, at the height of but 7 or 8000 miles above his surface (see note* page 96) to remain *undissipated* for above twenty days together, as some of them most certainly do (see page 80)? Or rather, does not the continuance of those clouds, for so long a time, amount to a demonstration, upon Sir *Isaac's* own principles, that no such heat exists, even within the denser regions of the sun's atmosphere?

an inconceivable ignition. Finally, had the Comet ever acquired so great an intensity of heat, it is probable the inhabitants of the earth would never have lost sight of it to the end of time; much less would it have totally disappeared in three months after its perihelion.*

Sir *I. Newton*, in making his computation of the heat sustained by this Comet, first took it for granted, "that the heat of the sun is as the density of his rays," (as we have seen before): In the next place, he considered the density of these rays with us, at the mean distance of the earth from the sun, as a fixed and certain standard, with which the density of the rays at every other distance might be compared: Then, after exposing dry earth to the summer sun, he compared the heat contracted thereby, with that of boiling water and red-hot iron, and found by experiments the proportional degrees of heat in them to be nearly as 1, 3, and 12 respectively: In the last place he considered the heat acquired by the dry earth aforesaid, as the standard of our summer heat, and annexed it to the mean density of the sun's rays with us:

* If the fixed stars be supposed equal in magnitude to the sun, and the Comet above-mentioned, equal to the earth; the period of the Comet to be *575* years, and its body be supposed sufficiently luminous to render it visible in all parts of its orbit; it appears from Mr. *Bradley's* determination of the parallax of the fixed stars, after a long series of observations (see *Smith's* Opticks, Vol. II. page 449 and onwards), that the apparent diameter of the nucleus of this Comet, must be much greater than that of the stars of the first magnitude, even when most remote from the sun and from the earth.

And upon this foundation he seems to have constructed his general scale of heat for the solar system. But it is presumed that the reader is by this time satisfied, that the main proposition upon which that great author's reasoning was founded must fail for want of support, however just his conclusions drawn from it may be: For we now find regions of eternal frost under the equinoctial itself, the rigours of which are scarcely exceeded in the polar regions; and this, at the height of but two or three perpendicular miles above the common surface of the earth, and where but few clouds interpose to hide the beams of the sun. If therefore we suppose ourselves carried up forty or fifty miles higher, or to the very top of the atmosphere, we may well shudder at the idea of such a situation, even if exposed to the unclouded rays of a perpendicular sun.

We are now naturally led to consider some extensive purposes which the great Author of nature probably had in view, when he formed the atmospheres of, and annexed them to, the several planets and Comets of our system. We have seen from indisputable authority, that the density of the sun's rays alone does not produce a competency of heat, for the comfortable subsistence of the inhabitants of the earth, even in its hottest climates, but, that a certain density of air is equally necessary, for these rays to operate upon, and to co-operate with them, in promoting the various purposes of life and vegetation. This air we are abundantly furnished with from the atmosphere which surrounds us, the density of which at every height, is proportional to the pressure of the incumbent fluid. We may conclude from analogy that the atmospheres of the other planets, and of the Comets, are designed for, and adapted to the same purposes for which the atmosphere of the earth was originally provided: And if we suppose the general stock of heat, which falls to the share of any planet, to be in a ratio compounded of the density of the sun's rays and the density of the air upon the surface of the planet, it is easy to conceive, that these globes may be severally furnished with such atmospheres, as may render them comfortable habitations, whatever their distances from the sun may be. That the heat of the sun is actually thus dispensed to the planets necessarily follows from the experiments and observations contained in the foregoing pages, upon the supposition that they are surrounded with aerial atmospheres, suited to their several distances from the sun; that they have such atmospheres is already proved, and the Creator, has, doubtless wisely proportioned their respective quantities and densities according to those distances.

The *tails* of Comets are nothing more than expansions of their atmospheres, whose lengths depend upon their nearness to the sun (as before observed) and decrease as they recede from the sun, becoming invisible to us (generally) before their *heads* disappear: Therefore we have the highest reason to conclude that when these globes are in the most remote parts of their orbits, or at their aphelia, their tails wholly subside, and their atmospheres resume spherical forms, like those of the earth and of the other planets, surrounding their nuclei at equal altitudes in every part; the sun's atmosphere being too remote to have any sensible effect upon them by its repellency. The air must of consequence be prodigiously dense near the surfaces of their globes, being compressed by the weight of such a vast incumbent fluid; whereby the sun's rays, though weaker, or less dense than with us in the ratio of the squares of the distances, may, upon our principles, be rendered as active with them, and as productive of such degrees of heat as are necessary for the purposes of animal and vegetable life, as with us, or any other planet of the system.

But, (as was observed by Dr. *Williamson*,) should these atmospheres continue of the same density, through all parts of their orbits, the degrees of heat which their inhabitants must undergo at their perihelia would be unsufferable: To prevent which, the great Author of nature has made sufficient provision; for as they approach the sun, they are by the repulsion of his atmosphere (or some other cause equivalent to such supposed repulsion) gradually eased of that incumbrance, the cometic atmosphere being gradually rarefied and driven behind its body through vast spaces of the heavens; what remains from time to time being more and more rarefied by the increasing action of the sun's rays upon it, and repelled as rarefied; till at length, if they come near enough to the sun, the inhabitants may have little more than pure æther to breathe in. Thus the Comet of 1769, (than which but few have gone nearer to the sun) before it arrived at its perihelion, although it projected a most astonishing tail, yet the remaining atmosphere was dense enough to hide the nucleus it surrounded; the Comet, when viewed through the best telescopes, presenting only a dubiously defined luminous appearance: But when it made its re-appearance in the evening about the latter end of *October*, its atmosphere had undergone so great a degree of rarefaction in passing its perihelion, that it was sufficiently pellucid to discover the nucleus, which appeared plainly and distinctly through it.

May we not then conclude, even with certainty, that as a Comet is perpetually varying its distance from the sun, so the density of its atmosphere is continually changing through the various stages of its revolution; and thence, that its inhabitants may at all times enjoy as much benefit, and receive as little injury, from the sun's rays, as the inhabitants of any other planet in the solar system?

As the primary planets revolve in orbits nearly circular, they have no occasion for such vast atmospheres as are necessary for the Comets in the remote regions of the heavens to which they retire; but are surrounded with such, as infinite wisdom saw best suited to their several distances from the sun; such as might have no redundancies to be thrown off in tails at one time more than another; the nearly equal distances of each from the sun, in the several parts of its orbit, requiring nearly an equal density of atmosphere at all times.

From the premises we may conclude, that the atmospheres of the inferior planets are smaller, and those of the superior ones larger in *some* proportion, than that of the earth, in order that their densities near their respective superfices, may be so proportioned to their several distances from the sun, as that they may equally share the benefit of his rays. For want of proper astronomical observations, to determine this point with regard to the other planets, we can pronounce with certainty only concerning *Mars*: As that planet is further distant from the sun than the earth, his atmosphere, for the reasons above assigned, ought to be larger than our own; accordingly it appears (from the observations referred to in Part I. Note *, page 78) that the height of his atmosphere above his surface is at least equal to two thirds of his diameter; which is much greater than that of the earth, though it falls vastly short of those of the Comets. Observations of future occultations of fixed stars by *Jupiter*, *Saturn*, and the other *planets*, made with better instruments, may possibly determine this point with regard to them also.

Several objections may be raised against the principles advanced in this Essay, to all which we hope to give satisfactory answers. As

1. It may be objected, that, as the *light* of the sun is confessedly proportional to the density of his rays, that is inversely as the squares of the distances from the sun, the inconveniencies arising therefrom to the inhabitants of the Comets, at their *perihelia* and *aphelia*, might be nearly as great as those which would arise from the sun's *heat* were it distributed in the same proportion; or at least, if it did not render the

Comets uninhabitable, would make the conditions of their inhabitants, at times very uncomfortable. For example, were the light of the sun adapted to their various purposes, at their *mean distances*, at their *aphelia*, they might not enjoy a sufficiency; and on the contrary at their *perihelia*, the splendor would be unsufferable.

This objection, it is presumed will vanish upon a careful attention to the structure of the eyes of terrestrial animals, whose pupils contract or dilate involuntarily, according as the density of the rays which pass through them and fall upon their retinas is greater or less, whereby more or fewer of those rays are admitted, as may be requisite for distinct, inoffensive vision: Thus most persons can see to read by candle light near as well as by day light, whereas the quantities of light reflected from objects in the two cases scarcely bear any proportion one to the other. But the aperture of the pupil is much greater in the former than in the latter, and more rays in proportion are consequently admitted. Moreover, there are some animals with us which retire to their holes and caves at the approach of day, whose purposes are as well answered by the glimmering light of the stars, as those of others are by the presence of the sun; there are yet others which can behold the sun in his meridian splendor, without offence. Now if we only suppose that the inhabitants of Comets in general have, in the original formation of their optic organs, the power of contracting and dilating their pupils, according to the strength or weakness of the light which is transmitted through them, we may easily conceive, that the rays of the sun might be no more offensive to them at one time than at another; for at their aphelia their pupils might be dilated to their utmost extent; on the other hand, at their perihelia, they might be contracted to physical points, if the splendor of the sun so required, whereby a proportionally smaller quantity would be admitted.

The light of the sun which the Cometarians enjoy at their aphelia is indeed much greater than we should be apt to imagine; for let us consider the Comet of 1680, whose period is the longest and its aphelion distance the greatest of any one known, being (according to Dr. *Halley*) to the mean distance of the earth from the sun nearly as 138 to 1; but from the reasoning of Dr. *Smith*, in his optics it appears, that the proportion of our day light to moon light with a full moon, is nearly as 90,000 to 1;* and the light of the sun upon the Comet at its last mentioned stage is to his light with us but as about 1 to 19,000, therefore if we divide 90,000 by 19,000 we shall find that moon light with us is to sun light upon the Comet, nearly as 1 to $4\frac{3}{4}$, and consequently that the light of the sun enjoyed by the inhabitants of that Comet at its aphelion is nearly five times as great as the light of our full moon. But it is still much greater upon account of the largeness and density of the atmosphere; for it is certain, that our day light, which is equally diffused upon all terrestrial objects, and renders them visible; depends upon the reflection of the sun's rays,

* Smith's Opticks, Vol. I. Page 29.

from the atmosphere, together with the heterogeneous corpuscles floating in it; without which all such objects would be as obscure as at midnight, even with the sun shining in full splendor above the horizon; excepting those upon which the direct rays of the sun might fall, or such as might be faintly illuminated by the reflection of those rays from neighbouring objects: The heavens would appear perfectly black, and the smallest stars would appear, at noon day, which is prevented, only, by the illumination of the atmosphere. The beautiful azure, which we observe in the sky, after the atmosphere is purged of its vapors, by a storm or thunder-gust, arises from the appearance of this black sky, through the air, which is now become more transparent, than when charged with a heterogeneous collection of opaque corpuscles.

The atmospheres of Comets, being much larger and denser than that of the earth, reflect a much greater proportion of the sun's rays; their hemispheres next the sun must therefore be more illuminated, and their day light increased, in the same proportion; although the light arising from the direct rays of the sun would be considerably weakened thereby.

This reasoning may be illustrated by calling to mind the effects of two great eclipses of the sun, one of which happened on the 5th or 6th day of August, 1766; the other on the 19th day of January, 1768; which effects, most persons among us, whose attention was turned that way, may recollect; during the former the air was very clear, and the sky cloathed in a fine blue, excepting, here and there, where a few summer clouds were scattered: In the midst of this eclipse the air was darkened to such a degree, that, although the sun shone unclouded, a sickly gloom seemed to spread over the face of nature. In the latter, (though a much greater eclipse) the air was full of vapors, the reflection of the sun's rays from which was so copious, as to render it offensive to the eyes to look at the heavens, before the eclipse began, and in the middle of it, the darkness occasioned thereby would scarcely have been noticed, had not the eclipse been known beforehand.

The inhabitants of Comets enjoy another advantage from their great atmospheres, which is peculiar to them alone; for, in the hemisphere turned from the sun, they can have no dark nights like those of the planets; but, in consequence of the reflections of the sun's rays from those atmospheres, must be favoured with perpetual twilight if not day light; for a cometic atmosphere is enlightened by the sun by night as well as by day, excepting only a column, which is nearly cylindrical at the aphelion, whose base is a great circle of the Comet, and whose altitude is equal to the height of the atmosphere; which, (considering the great extent of the latter,) bears but a small proportion to the whole atmospheric hemisphere; this column includes that part of the atmosphere which is eclipsed by the shadow of the globe itself, and, if the diameter of the atmosphere is equal to ten diameters of the globe,* does not contain $\frac{1}{60}$th part of the whole visible hemisphere; and is still less upon account of the refraction of the sun's rays, which shortens and contracts the cone of the shadow. Whence it is probable that the darkest nights of the Cometarians, at their aphelia, are much lighter than our brightest moon light nights. But this is submitted to the judgment of the reader.

2. It may further be objected; that if the atmospheres of Comets undergo such amazing rarefactions and condensations, as they necessarily must, from the alternate projections and retractions of their tails, it is difficult to conceive that they can at all times be fit for the respiration of their supposed inhabitants.

This objection might, perhaps, have remained unanswerable, had it not been for the genius of that truly great philosopher Doctor *Edmund Halley*; who, if he was not the original inventor of the *diving-bell*, yet, by a sagacity peculiar to himself, improved it to a degree of perfection, which might, before, have rather been wished for, than expected.† In this *bell* persons may be let down with safety to the bottom of the sea; but the included air differs in density at every depth below the surface of the water. At the depth of thirty-two or thirty-three feet, as the air may occasionally change, or less, in proportion as salt water is heavier than fresh, the density of the air within the bell is

* See Page 79.

† See Jones's Abridgment of Philos. Trans. Vol. IV. Page 188, and onward.

double the density of the external air; at double that depth the density is triple; at three times, fourfold, and so on. Now if the bell be let down without proper precaution, the too sudden condensation of the air within, would give the adventurers extreme pain, as they sometimes found by experience; and should the bell sink suddenly to the bottom of the sea, the consequence might be fatal to them; for the same reason that a square case-bottle, filled only with common air above the surface of the water, and corked tight, if it were let down with the divers in the bell, would from the increasing pressure of the condensing air without it, be crushed inwards, and broken in pieces, in the same manner as if the air in the bottle had been exhausted by an air-pump above the surface of the water; which effect would be prevented by the smallest hole in the cork, provided the bell were let down leisurely, so that the air as it condensed without, might gradually insinuate itself through the hole into the bottle: On the contrary were the bottle corked at the bottom of the sea, and the bell drawn up from the depth of nine or ten fathoms; before the bell could arrive at the surface of the water, the bottle would burst outwards, from the expansive force of the condensed air within it; which might also be prevented by a similar precaution. And it is doubtless from the latter cause that some persons who have ascended to the tops of high mountains, have been seized with reachings, vomitings and other inconveniences related by travellers; the external air of the atmosphere at such heights being too rare to counteract by its pressure, the expansive force of the denser air which is interspersed throughout the various vessels and organs of animal bodies.

But Doctor *Halley* testifies from his own experience, that "if the diving-bell be let down (or drawn up) "gradually, about twelve feet at a time with an inter-"val of but a few minutes between, no inconvenience "would follow;" as the several organs of the body would by degrees be inured to the density of the air, as it increased or decreased at the several depths. The doctor tells us, that he himself was hours together at the bottom of the sea in nine or ten fathoms of water; and felt himself as well as if he had been all the time on board the ship: but the density of the air he then breathed, must have been more than three times as great as that of the air above the surface of the water: in other words, he then breathed in air, compressed by the weight of between three and four of our atmospheres instead of one, and of ten or a dozen such as *Don de Ulloa* breathed in, when upon the tops of the mountains of *Quito*, without any inconvenience. Therefore, if time sufficient be allowed for the air, included in the several vessels of the human body, gradually to contract, expand or otherwise accommodate itself, to the increasing or decreasing density of the exterior air; no bad consequences or even inconveniences are to be apprehended, although the difference of density be exceeding great.

But by the gradual and regular approach of any Comet to, or recess from its perihelion, (at and near which its velocity is greatest and the consequent changes in its atmosphere are most sudden of all) the increase or decrease of the density of its atmosphere, is much more regular, uniform, and insensible to its inhabitants, than any increase or decrease of the density of the air can be in the diving-bell by Doctor *Halley's* method; for by the latter, a degree of rarefaction, or condensation, is effected in a few minutes, which might not take place in the cometary atmospheres under some days.

Perhaps enough has been already said to remove every material objection; but if any difficulties yet remain, in the mind of the reader, on account of the vast changes which the several climates in each, and the atmospheres of all Comets must necessarily undergo, in the various parts of their orbits; the following additional observations are submitted to his consideration; which may tend to lessen those difficulties, if they do not wholly remove them, viz.

As a Comet approaches its perihelion, that hemisphere of its atmosphere which is next to the sun, being more immediately exposed to his rays, will feel the effects of his neighbourhood sooner than the opposite hemisphere, and consequently will be warmed, rarefied, and thrown off behind the Comet by the repulsion of the sun's atmosphere, sooner than the other; the colder and denser parts of the fluid will of course continually flow in from the other side of the Comet to supply its place, in order to preserve, as near as may be, an equilibrium; in consequence of which there will be a constant succession of the cooler air from thence; whereby the inhabitants on the hemisphere next the sun may be continually refreshed with gales of wind during that vicinity, which would increase till the Comet arrived at its perihelion, when their velocity would be greatest of all; but even then they would not (from this cause) blow in sudden violent gusts like our hurricanes, but steadily, unless disturbed by causes from within the Comet's atmosphere; besides, as the velocity of the current increased, the density of the fluid would lessen from the increasing rarefaction, whereby its momentum might continue nearly the same; for this momentum would be in a ratio compounded of the velocity of the fluid and its density together; and as the violence of our high winds, and their consequent effects depend, not upon the velocity, merely, but upon the momentum of the current, this brisk circulation of the cometic air may, (however great we suppose its velocity) be rather grateful than injurious to the *Cometarians:* and how unfit soever the air in such a rarefied state might be for their use, if stagnant, yet, when thus put in motion, it may be rendered sufficiently active to answer all the purposes of respiration. This reasoning is confirmed by daily experience: for it is not an uncommon thing for people of tender frames to faint in a close hot and rarefied air; and as the fan is generally near at hand, it is as common for the bye-standers to apply it to their faces, which, by giving a brisk motion to the air, without any alteration of its density, generally revives them, in a short time, even when no other remedy is at hand.—This brisk motion of the air would also remove or prevent the disagreeable sensations of heat which the *cometary* inhabitants might otherwise suffer from an exposure to the sun's rays at their perihelia: For, if a person sit with his face uncovered before the scorching blaze of a common fire, the motion of the air excited by a common fan, even without hiding the blaze from the face, is sufficient, not only to make the situation comfortable, but to change the painful sensation to an agreeable coolness: as any one will find upon trial.

If we suppose that every Comet has a diurnal rotation round an axis of its own, the inhabitants may enjoy grateful vicissitudes, from the alternate absence and presence of the sun; and if we further suppose this diurnal motion to be performed contrary to its apparent heliocentric motion; the returns of day and night would be quickened as it approached the sun, from the increase of its angular velocity round that globe, whereby the presence of the sun by day, in that neighbourhood, would be of shorter duration, upon any one part of the Comet than when it is in the remoter parts of its orbit; and his heat might be rendered still less irksome to the inhabitants, on that account. It is true, no discovery has been made of any such diurnal motion, but as all the primary planets, so far as our observations can reach, are discovered to have such motions, we may well be allowed to suppose that the Comets are not without them; especially now we are endeavouring to prove their habitability, to which this motion is perhaps as necessary as to the habitability of the primary planets. These rotations have been already discovered and determined in *Venus*, the *Earth*, *Mars* and *Jupiter*. *Saturn*, though a vast globe in itself, is so remote, and *Mercury* is so near the sun, and so very small, that this motion has never been discovered in either, by our best instruments, but is justly inferred by analogy; which method of reasoning will equally extend to the Comets of the system. The diurnal motions of the planets indeed are performed nearly in the same directions with their annual, both motions in all, as far as they have been discovered, being direct, or from west to east, whereas the diurnal motions of Comets, according to the foregoing supposition, are performed contrary to this rule: But this is no objection against the hypothesis; for planets and comets differ as widely, in almost every other particular; the annual motions of the former (as now observed,) are all direct, and are apparently confined within the limits of the zodiac, the latter move indifferently in all directions through the heavens; the periodical revolutions of the former are made in orbits nearly circular, those of the latter are prodigiously excentric, and nearly parabolical; all which seem wisely to be ordered, that a multitude of worlds may exist at the same time, and be enlightened, warmed, and rendered prolific, by the rays of the same sun, without interfering in their motions, or disturbing the harmony of the system.

To illustrate the reasoning in pages 148, 149, Fig. 5 is added; in which let S represent the sun; to which Comets in general, though perhaps equal in magnitude to our earth, are, without a *figure*, but as *drops of the bucket*.* Let C represent a Comet with its atmosphere and tail, the dark curve line *c k d g h* on one side, and *c i a e f* on the other, may serve to give an idea of the motion of a parcel of the cometary air from its more condensed state behind the Comet at *c*, through its various stages of rarefaction and repulsion; as that part of the atmosphere next the sun, viz. that in or near the line S *b* which connects the centres of the sun and the Comet, is rarefied, the denser air from behind at *c* must necessarily flow in to preserve as near as possible an equilibrium, and continue so to do as long as the rarefaction continues to increase. The air next the sun being thus rarefied, that at *c* would take a turn round the nucleus through *k* and *i*, but before these separate parcels came to *d* or *a* the rarefaction would so increase, that they would begin to ascend, and as they ascended, at *a* and *d* they would repel each other; they would still keep rising by their increasing rarefaction, through

* In the figure the speck at X and the dots round it, upon the surface of the sun S, will give a pretty just idea of the comparative magnitudes of the sun and Comet, and of their atmospheres; the dots at X representing the Comet's atmosphere, AAA, &c. the atmosphere of the sun.

S *b* as through a funnel, and increase in their mutual repellency as they receded from the centre of the Comet, till at length at *l* and *m* the repellency of the sun's atmosphere would compel them to retire through *g h* or *e f* whence they would proceed to the extremity of the tail, the remaining parcels of air in the same cometic hemisphere would take a similar course (as represented by the faint strokes in the figure) whether their distances from the Comet's surface were greater or less, till at length the rarefaction of the Comet's atmosphere would become as great, as the repulsive power of the sun's atmosphere could effect, or the Comet's vicinity to the sun, require.— We shall offer one observation more, for the consideration of the reader before we close the subject, viz.

When the air of our atmosphere appears by the thermometer to be extremely cold, it does not effect the senses so disagreeably, if the atmosphere be in a calm stagnant state, as at other times, when the mercury is ten or even twenty degrees higher, (and consequently the weather warmer) with a brisk wind, as has been frequently observed by those who attend to their thermometers. Now when a Comet is at its greatest distance from the sun, its atmosphere, being uniformly condensed round its globe, might settle into a dead calm, for any disturbances it could receive from without: For whatever influences baneful or salutary, the heavenly bodies may reciprocally communicate while in the neighbourhood of each other, the Comets in their aphelia, are removed to such inconceivable distances from all the other globes of the system, that their mutual effects, physically considered must vanish. And in so calm an atmosphere, of so great a density, illuminated by the sun's rays, the inhabitants of the Comets may, even when most remote from the sun, be as warm, or at least as comfortable as the inhabitants of the earth, or of any other planet.

This subject cannot be better closed than in the words of Doctor *Williamson*, viz.*

" One of the primary ideas we form of the supreme
" Being is, that he is the source of life, intelligence
" and happiness, and delights to communicate them;
" the earth we tread, the water we drink, and the very
" air in which we breathe, swarm with living crea-
" tures, all fitted to their several habitations.—Are we
" to suppose that this little globe is the only animated
" part of the creation, while the Comets, many of
" which are larger worlds, and run a nobler course,
" are an idle chaos, formed for the sole purpose of
" being frozen and burnt in turns?——We cannot
" admit the thought; the Comets are doubtless in-
" habited."

* See Transactions of the American Philosophical Society of Philadelphia.—Appendix page 30.

APPENDIX.

If we suppose all the solid globes of the solar system to be annihilated, their atmospheres remaining; the power of gravity, which had theretofore condensed them round their respective orbs, ceasing, they would immediately expand themselves *quaqua versum*, in consequence of the mutual repellency of their particles, till the whole space in which the bodies of the system had revolved, was equally filled with the fluid, and when its density became equal in every part, the whole would be at rest.

So, *vice versa*, if we suppose such a fluid, to have been the first material substance in the order of creation, equally diffused, in that rarefied state, throughout the mundane space; next after it, the several masses of the sun, planets and comets, nearly about the same time with each other: This fluid, though its particles are in a state of mutual repulsion, yet as they are in the common state of gravitation to the other bodies of the system, would be attracted by the several globes, every particle moving towards that globe, which should have the balance of attraction in its favour.

Mercury's atmosphere, by reason of its neighbourhood to the sun, and the smallness of his globe would be least of all and very inconsiderable: For suppose a right line A B.

drawn from the centre of the sun to the centre of *Mercury*, to be so divided in D, that the part next the sun may be to the part next *Mercury* in the sub-duplicate ratio of the quantity of matter in the sun to the quantity of matter in *Mercury*; every particle between D and B would descend to, and be condensed round the sun, and those only between D and A to *Mercury*; and it appears by computation that DB : DA : : 3693 : 1 nearly, and in all oblique directions the particles, whose distances from the sun and Mercury were proportionably greater or smaller, would descend to, and condense round one or the other; unless drawn aside by some other planet: What is here said of *Mercury*, is equally applicable to the other planets; and as the attraction of the sun is vastly greater than the united attractions of all the planets together; so, in every part of the system, where the attractive power of the sun might be greater than that of any neighbouring planet; the fluid occupying that part of the space, would descend and join the sun's atmosphere; while the rest would be continually condensing round the planets, till at length the several globes would be accommodated with their proper atmospheres, when the heavens would be left a perfect vacuum for the various bodies to revolve in, without the least resistance.

If the Comets be supposed to have been created and projected in their several orbits, at their aphelia, or at their greatest distances from the sun, it may be easy upon this hypothesis to account for their having atmospheres so much exceeding those of the planets in their dimensions; for providence has so ordered it, that the angles of the inclinations of their orbits to the ecliptic, and to each other, are generally very great, and their motions are directed to all parts of the heavens indiscriminately, whereby their distances from the planets and from each other, at their aphelia, are great beyond human conception; consequently they were at liberty to share amongst themselves, without any molestation from the planets, all that part of the fluid, which filled the vast spaces of the system, without the planetary regions; therefore if the hypothesis be granted, they must necessarily have such atmospheres, as, in fact, we find they have, and which, in their descent through the planetary spheres, are, by the (supposed) repulsion of the sun's atmosphere, driven to such astonishing distances behind them, as occasion may require. Those whose aphelion distances were greatest, being more solitary, would condense round them the greatest atmospheres, and such, their greater distances from the sun would require, upon the foregoing principles, to make them comfortable habitations. As the lengths of their tails would probably, at equal distances from the sun, be proportional to the quantities of this repellent matter contained in their atmospheres respectively, it may not be impossible to form a rational conjecture of their real aphelion distances, by observing the apparent lengths of their tails, when at equal distances from the sun, in their descent, and thence computing their real lengths, and comparing those whose aphelion distances are unknown with those which are already determined; and as nearly as we can by this method come at their greatest distances from the sun, so nearly may we (by comparing their computed trajectories, with those distances,) determine their mean distances and periodic revolutions. But this is humbly submitted to better judges, and is designed only as a hint for future inquiries.

Fig. 6

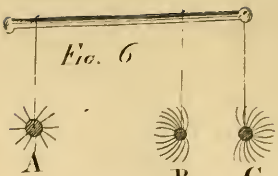


Fig. 1

Fig. 2

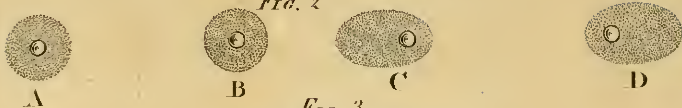


Fig. 3

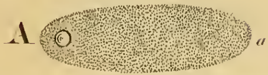
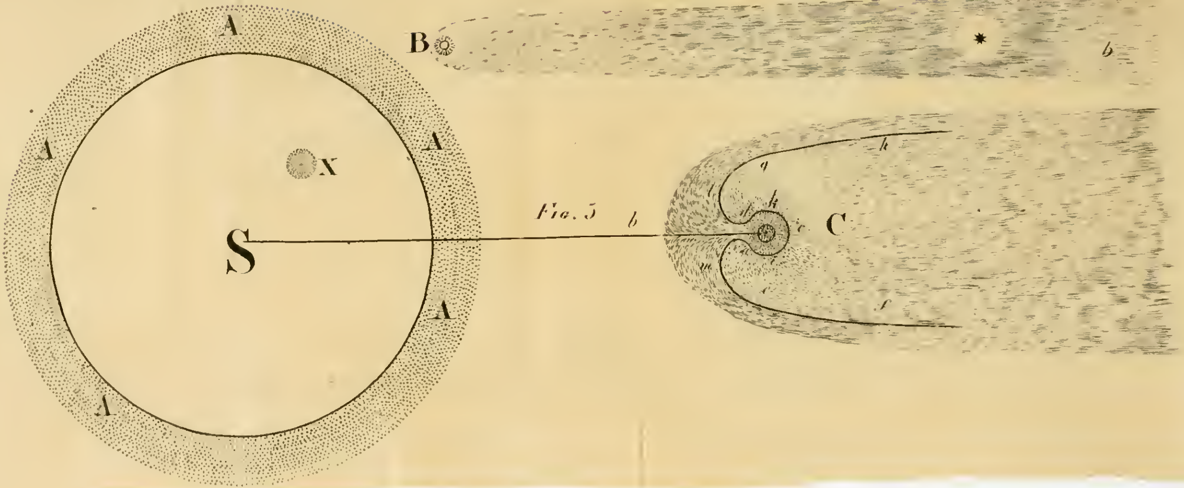


Fig. 4

Fig. 5



SUPPLEMENT,

CONTAINING AN ACCOUNT OF THE COMET OF 1811, WITH INCIDENTAL REMARKS.

THE Comet which we have had the gratification of beholding, more than three months, and which is still faintly visible, [Dec. 20] has been more brilliant and striking than any which has been seen since 1769. In Boston, it was first noticed on the 4th of September by a gentleman riding into town in the evening. It had been seen, some days previously, at Portland, in the morning, by two gentlemen who rose, at an early hour, to take seats in a stage. Its first appearance was faint and nebulous. On the 6th of September it was very conspicuous, and was ascertained to be a Comet. Professor Farrar's first observation was made on that evening, at Cambridge. It was then under the square of *Ursa Major*. This Comet was seen at Vivieres in France, on the 25th March last, by M. Flaugergues; at Marseilles on the 11th of April by M. Pons; and at Paris on the 20th of May. It continued visible there, till the end of May; and it has been announced, in some of our public papers, that a Comet was observed in May, at Chilicothe.

M. Olbers, of Bremen, in a letter to Professor Boden, which has been published, announced that it would re-appear before the end of August, that it would be much more visible than in the spring, that its greatest brilliancy would be in October, and that it would still be visible in December. This has all been verified. It was seen again, both in France and in England, on the 21st of August. It then "had "the appearance" says *Capel Lofft*, "of a large Ne-"bula, nearly circular, and of about one degree in dia-"meter, with a central light, like that of Andromeda, "resembling a hazy star of the fourth or fifth mag-"nitude. Right ascension, 149° or 150°. North de-"clination, nearly 36°." On the 6th of September, it was considerably brighter, and M. Lofft observes, that its train then, viewed with good glasses, was "evidently divided by a darkish shade near the far-"thest extremity." On the seventh of September, he describes its train as about 6 degrees in length: the breadth of the head, including the diffused Coma, about $\frac{1}{4}$ or $\frac{1}{5}$ of the moon's apparent diameter. Observations on this Comet, have been made, in different parts of the United States, with laudable attention, and have been occasionally published in the newspapers. The elements of its orbit were given by Nathaniel Bowditch, Esq. of Salem, in the following communication, published October 11, in the Salem Gazette.

"The geocentric longitudes and latitudes of the Comet, used in finding the elements of the orbit, were deduced from distances of the Comet from *Arcturus*, *Lyra*, and *Dubhe*, observed at Cambridge by Professor Farrar, and at Nantucket by the Hon. Walter Folger, jun. By combining the observations of September 6, 9, 12, 15, 18, and 23, the elements of the orbit were found by the method of La Place, and corrected by the observations of September 6, 15 and 23.

"Perihelion distance, 1.052. The mean distance of the earth from the sun being 1.

"Time of passing the perihelion September 6, 1811, at 18h. Greenwich time.

"Place of the perihelion counted on the orbit of the Comet, 2s. 21d.

"Longitude of the ascending node, 4s. 18d.

"Inclination of the orbit to the ecliptic, 74d.

"Motion retrograde.

"These elements will require some corrections, (perhaps two or three degrees) to be determined when a greater number of observations, on a longer arch of the orbit, shall be made. The observations made early in September were liable to a small error, from the uncertainty of the refraction, the Comet having been observed near to the horizon.

"These elements differ from those of all the Comets whose orbits have been calculated; as may be seen by examining the tables of La Lande and Vince, or that in Rees's Cyclopedia under the article 'Comet.' This Comet is therefore one that has been before unknown to astronomers.

"Wishing to estimate nearly the apparent course of the Comet from these elements, I described a circle on a stiff piece of paper to represent the orbit of the earth, and a parabola corresponding to it, for the orbit of the Comet (similar to fig. 267. vol. 3. edit. 3. of La Lande's Astronomy) and marked on these curves the places of those bodies for each day of the present year. A slit being cut through the circle in the direction of the line of nodes, the parabola was inserted so as to be inclined to the ecliptic by an angle of 74°, the point representing the perihelion being above the plane of the ecliptic, so as to make the angle at the sun by the perihelion and node 57°. By this apparatus, the following estimate of the apparent course of the Comet and its distance from the earth were made.

"In the month of February 1811, the Comet was near to the eastern part of the constellation Argo. Its motion was then west, inclining to the north. It passed a few degrees to the eastward of the Great Dog, and its direction then became nearly north, being stationary in longitude in the month of May. It passed near to the eastern part of the Lesser Dog, early in June, inclining rather towards the east. On the 16th of July it passed the ascending node in the longitude of about 4 signs 8 degrees, and then moved northeasterly towards the feet of the Great Bear, where it was first seen, after the conjunction with the sun, on the sixth of September. On the 5th of October it was near the right hand of Bootes. It will be at its greatest north latitude about the middle of October, near the right foot of Hercules, after which it will begin to move towards the ecliptic, through the left knee of Hercules, towards the Eagle, the Dolphin, the Water-Bearer, &c. It will be near the Eagle about the first of December. It is to be observed that the apparent positions thus roughly estimated, are liable to an error of two or three degrees. The orbit of the Comet falls without the earth's orbit.

"The distances of the Comet from the earth, expressed in parts of the sun's distance from the earth, estimated as 10, were found in February 1811, to be 30; in June, when visible at the Cape of Good Hope and at other places south of the equator, 23; on the 6th of September, 17. About the middle of this month (October) it will be at its least distance, 13; after which it will increase, and in the month of December it will be about as far distant as in June. In the latter part of January, and in February, 1812, the distance will be above 30; the latitude of the Comet will then be small; and as it will be nearly in conjunction with the sun, it will probably then be invisible. The least distance of the Comet from the earth is about 120 millions of miles. The least distance of the Comet from the sun, 100 millions of miles.

"The tail of the Comet has been observed to be 10 or 12 degrees in length, which would make its real length nearly equal to half the distance of the earth from the sun."

On the 1st of November, the following additional observations were inserted, by Mr. Bowditch, in the same paper.

" In the account of the Comet published in the Gazettee of the 11th ult it was observed that each of the elements might require a correction of two or three degrees, on account of the shortness of the arch described in the interval between the observations used in those calculations. To determine nearly those corrections, the observations of September 6 and 30, and October 21, were combined, which furnished the following corrected elements:

" Perihelion distance 1,032, the mean distance of the sun from the earth being 1.

" Time of passing the perihelion September 12th, 3h: 1811, Greenwich time.

" Place of the perihelion, counted on the orbit of the Comet, 2s. 15d. 14m.

" Longitude of the ascending node, 4s. 20d. 24m.

" Inclination of the orbit to the ecliptic, 73d. 0m.

" Motion retrograde.

" These elements give the geocentric longitudes and lattitudes of the Comet from September 6 to October 21, very nearly as they were observed. It may however be necessary to apply some small corrections, to be determined by repeating the calculation with a greater number of observations.

" These small variations in the elements do not produce any great change in the apparent path, and in the distances of the Comet from the earth given in the former paper."

The well known accuracy of Mr. Bowditch, in calculations of this sort, induced a reliance on the correctness of these results, with the qualifications expressed; and the public felt indebted to that gentleman for his early attention to the subject.

Mr. Bowditch's calculations of the Comet of 1807, were published in about six weeks after its first appearance. They may be seen in the Memoirs of the American Academy of Arts and Sciences. vol. iii. part 1.

In the Journal De Physique, for August 1808, the elements of the same Comet are given by an European astronomer, Mr. Bessel, adjunct with Schroeter, at the observatory near Bremen. The coincidence is striking, and in every view gratifying, as it fixes our confidence in calculations of this description. The differences between the two calculations, is only thus:

In the time of passing the perihelion	2 hours 27′ 34″
In the longitude of the ascending node,	21′
In the place of the perihelion,	1′
In the inclination of the orbit,	53″
In the perihelion distance,	,00314

We fortunately have it in our power to compare Mr. Bowditch's calculations, of the present Comet, with those of another eminent calculator, in France, M. Burckhardt. The elements of this Comet, as published by him in Paris on the 20th September, are as follow:

Perihelion distance,	1.0224

Moment of passing the perihelion, September 12, 9 o'clock P. M. 48m.
Ascending node, 140° 13′ or 4s. 20d 13m.
Inclination, 72° 48m.
Place of perihelion, 74° 12 or 2s. 14d. 12m.

The differences, it will be perceived, between the American and French results are very trifling, and leave no doubt of their near approximation to the truth. Speaking of the perihelion, M. Burckhardt adds "since that time, the distance of the Comet from the sun has increased, but the distance from the earth will continue to diminish till towards the middle of October. Then, the least distance from the earth to the Comet will be upwards of 41 millions of leagues."

Mr. Bowditch's results have thus obtained most respectable support, and are fully vindicated, if vindication were necessary, from the animadversions made by Mr. John Wood, in the Richmond Inquirer. That gentleman contends, that the Comet had not come to its perihelion on the 1st of October. To these remarks, Mr. Bowditch gave a brief, but satisfactory reply in the Salem Gazette of November 15. Mr. Wood's strictures are more exceptionable, as they were hazarded without any calculations, from the numerous observations which he had made with commendable industry, and probably with correctness. His conclusions are founded on appearances, in their nature equivocal, and which were capable of a ready solution, in perfect consistency with the results of Mr.

Bowditch's investigations. Mr. Wood, for instance, contends, that the motion of the Comet was *direct* and not *retrograde*, as stated by Mr. Bowditch; and that the inclination, instead of being 74 degrees, cannot exceed 64 degrees. This remark is at once answered by Mr. Bowditch, by observing, that he gives the proper motion and angle of inclination, in reference to the sun, according to uniform practice. Mr. Wood has reference to a view from the earth. It may be here observed, that the same Comet during its appearance, may be direct and retrograde at different times, as seen from the earth. The apparent motion of the present Comet, in February and March 1811, was retrograde, but it is now direct. Mr. Wood has observed that the method of La Place, and all other methods, leave great uncertainty in the results. "I am confident," says Mr. Bowditch, "that this assertion would not have been made, had he been acquainted with that elegant method of calculation." And as to the opinion expressed by Mr. Wood, that till a greater number of observations should be obtained, any calculations of the elements must be extremely erroneous, Mr. Bowditch observes, "In this Mr. Wood is much mistaken. The Comet has now been visible above two months; and it is not unusual in Europe to have the elements of the orbit of a Comet, to a considerable degree of accuracy, in a week or ten days after its first appearance."

In the London Courier of October 9, we find the elements of this comet given by Andrew Ure, from observations made at the Glasgow Observatory. The calculations are from five observations, made on the 1st, 8th, 15th, 23d, and 30th of September, the formula of La Place were pursued, and Mr. Ure was assisted by Mr. Cross, his mathematical associate in the Andersonian Institution. These gentlemen give, as the result of their calculations, the perihelion distance 94,724,260 miles.

Time of the perihelion, September 9.

Comet's distance from the earth, September 15, 142,500,000 miles.

Comet's distance from the sun on the same day, 95,258,840 miles.

Distance of the earth from the sun, at that time, 96,505,932 miles.

Length of the tail 33,000,000 of miles.

Motion of the comet retrograde.

According to this calculation the perihelion distance was about 170,000 miles nearer to the sun, than the mean distance of the earth from that luminary. There is a difference of three days in time from that given by Messrs. Burckhardt and Bowditch. The place of perihelion, longitude of the ascending node, and inclination of the comet's orbit, are not given.

Mr. Ure, having afterward seen M. Burckhardt's account, thought it necessary to add some explanatory remarks. "The talents of M. Burckhardt as a computer," he observes, "are well known, and highly appreciated by the learned world;" but he still expresses a confidence in the elements he had communicated. "The time of the perihelion passage," he says, "may be pretty accurately fixed either for September 12, or 9, or, as is more probable, at some intermediate period."

It was gratifying to find the elements of this comet presented to the committee of the overseers of the University in Cambridge, at an exhibition on the 22d of October, calculated by one of the students of the senior class, and accompanied with a neat graphical representation. The following were the results as given in that young gentleman's performance.

1. Perihelion distance 1.1, the earth's mean distance being 1.

2. Time of passing the perihelion, September 6.

3. Place of perihelion, 2s. 22°.

4. Place of ascending node, 4s. 15.

5. Inclination, 77°.

6. Motion retrograde.

7. Passed the ascending node July 27.

8. Distance from the earth's path when on the node, 34,600,000 miles.

Diameter of the comet, including the coma immediately surrounding it, 132,200 miles. The apparent diameter, as measured by a micrometer, being 2′ 46″.

Diameter of the nucleus, estimated at about half the diameter of the earth. Its apparent diameter could not be measured by the micrometer, the nucleus being too indistinct.

The length of the tail, 70,000,000 miles; the angle under which it was seen, October 19, being 14° 30′.

These results have been obligingly communicated by Professor Farrar, upon request. He observes that they were obtained by the graphical method, "six "geocentric latitudes and longitudes being employed, "viz. those for the 6th, 14th, 20th, 24th, and 30th of "September, and 17th of October. A paper was "stretched upon a plain board, to represent the eclip-"tic, on which was drawn the path of the earth, and "its place for the above times: From these several "points were set off the elongations of the comet, "and threads raised to represent the latitude. This "being done, different parabolas, divided into days, "were applied, the focus being kept in the sun, until "one was found which gave, nearly, the observed "places of the comet."

"Great accuracy," he adds, "is not to be expected "from this method, particularly in the time of pass-"ing the perihelion, when no very considerable ine-"quality in the motion of the comet takes place, dur-"ing the several intervals between the observations."

To Professor Farrar we are indebted also for the following communication.

"From September 6, to December 10, the comet "described an arc of about 121°, as seen from the "earth. When it first appeared, it moved at the rate "of about 1° per day. Its velocity increased till it "amounted to a little more than $1\frac{3}{4}$° per day, and "then began to decrease till about the middle of No-"vember, when it returned to its former rate of 1°; "and now, 10th December, it is about three fourths

" of a degree. It came within the circle of perpetual " apparition, about the 20th of September, and con- " tinued about 20 days. It reached its greatest nor- " thern declination, 50°, near the 2d of October, and " its greatest northern latitude, $63\frac{1}{2}°$, about the 17th. " At this time also its motion in longitude was at its " maximum. On the 6th of September, when it was " first seen, it was about 18°, west of the sun in " longitude. After continuing for some time at about " the same distance, it gained upon the sun, and about " the 11th it came up with it, and passing it, arrived " at its greatest elongation, 53°, about the 10th No- " vember. From this time it has been continually " falling back, with respect to the sun. It loses now " at the rate of more than half a degree per day; and " this quantity is increasing, and of course must soon " reduce its present direct distance, 46°, within the " compass of the twilight, when the comet will dis- " appear, again to come into conjunction with the sun. " After which the sun will move on to the east of the " comet, leaving the comet behind, to pass off into " the southern hemisphere. The comet will now rise " in the morning before the sun; and, when it gets " out of the twilight, may perhaps be seen again by the " help of the best glasses. Its present distance, from " the earth, is about double what it was when in pe- " rigee."

M. Burckhardt, in his communication above mentioned, makes the following interesting remarks. " The nucleus of this comet appears separated from "its *coma*, which surrounds it in the form of a parabolic ring. This appearance, which has not yet been observed in other comets, is ascertained by the observations of all the astronomers of Paris, and will doubtless be confirmed by those of other astronomers. Probably, however, it does not at all follow, that the body is absolutely detached from the *coma*, as the space, which appears void, may be filled with particles much less luminous than the rest of the *coma*."

The description given by M. Burckhardt is confirmed by Professor Farrar's observations, as will appear by an extract from his minutes. "September 18, observed a kind of dark ground, round the head, for the space of four or five times its diameter, and then a luminous appearance, somewhat resembling a halo, on the side opposite to the tail, very apparent, even through an achromatic refractor. It struck me as a peculiarity, and I called several persons to look at the comet, and to describe to me its appearance. They made the same observation; and one compared the form of this light to that of a current of water, flowing round a stick, or other obstacle. A slight sketch was copied upon paper; but, upon looking into Hevelius, I found that some of the representations, which he had drawn from mere verbal descriptions, agreed so far with what I had remarked in this comet, that I ceased to regard it as altogether new."

The Rev. Dr. Prince, of Salem, who made repeated observations on the comet with an excellent night glass, makes the following remarks in a letter to a friend. "I saw it more distinctly about the middle "of October, than at any other time. The tail was "very much forked, the light being very strong on "the two sides of the tail, and very faint towards the "middle. In some part, included between the head "and two points of the tail, the space appeared as "dark as on the outside of the comet, or the unillu-"minated part of the heavens. The forks were taper-"ing to a point. I could discern a little more light in "the space about the axis of the cone, which formed "the tail, when I moved the glass, than when it was "at rest, but the light was gradually diminished from "the two inner sides of the forked tail, till it wholly "disappeared, near the axis toward the end. This is "what is called a bifurcated comet, and appears in "my night-glass more pointed or angular than when "seen with the naked eye. Its appearance is different "from the comet seen here in 1807, the tail of which "spread with a uniform light."

La Lande's table comprehends 78 comets, the elements of whose orbits have been ascertained. It ends January 1790. In the Journal De Physique for August 1808, a supplementary table is given, presenting the elements of 19 more, all subsequent to January 7, 1790, and many of them calculated by the celebrated Olbers. This table ends with the comet of 1807, which, of course, combining the numbers of the two tables, is the 97th comet, and the comet of 1811 is the 98th.

The table inserted in Dr. Rees' New Cyclopædia (American edition) includes three comets not contained in La Lande's table. One of 539, A. C. one of 1097, A. D. and one of 1351. Of the last the elements are only partially given. In De La Lande's tables, also, the comet of 1532, and 1661, are considered as one; and that of 1556, the same as that of 1264. This makes a difference of *five*, between the two tables, in their enumeration. Dr. Rees' numbers are more conformable to the opinion expressed by La Place, and other astronomers of eminence, that the return of but one comet is ascertained—that of 1759, which corresponds with the elements of three preceding appearances, at intervening periods very nearly equal. By Dr. Rees' plan of enumeration, the comet of 1811 would be the 103d.—These registers are of important use in this branch of astronomy; and it is desirable that some uniform system of enumeration should be adopted. It is obvious, from these tables, that the number of comets is very great. Their increased frequency is observable within the last fifty years, when the attention of astronomers has been more particularly directed to the subject. In the whole 17th century we find but fifty-five recorded. But from 1757 to 1800, forty-three have been observed, being, on an average, one in a year. In the present century there have already appeared *eight*—Most of these, however, are without eclat, and would have travelled through our hemisphere unobserved, if they had not been sought. Their frequency becomes observable, from the time when astronomers were exploring the heavens, with unwearied assiduity, eager to recognize the re-appearance of the comet predicted by Halley.

Philosophy, says Dr. Adam Smith, is the science of the connecting principles of nature; and in his admirable fragment on the history of astronomy, he ingeniously illustrates, on principles of human nature, the reception of the several schemes, which at different times have been suggested, to explain the various appearances of the celestial bodies. Curiosity could not but be excited on the subject. Any plausible solution, which gave repose to the imagination, whether solid orbs, concentric spheres, or vortices, would, for a time, be sustained, and give way only to demonstrative truth, the result of persevering investigations. At length, to mere inventions of the imagination, succeeded the grand Newtonian theory, which has stood the test of the most severe scrutiny, and now remains unquestioned. When this theory was extended to comets, and their analogies to the planets, in regard to the laws of their revolution, were settled, the mind would seem to have been satisfied, if some very striking differences, distinguishing them from the planets, had not been constantly observed. The full explanation of these differences, is still a desideratum in this branch of astronomy. In regard to plane astronomy, the doctrine of comets seems to be well determined. In addition to the elements recorded in the tables, the magnitudes, distances, velocities, and in many instances, the densities, of those which have appeared, have been settled on sure principles of science. But the phenomena of those immense luminous trains, which so strikingly distinguish them from the planets, have not yet been explained, so as to gain that general and entire acquiescence, which attends the other branches of astronomical science. Perhaps the difficulty has arisen from a too hasty adoption of schemes of thought, relative to their destination and use. The surer way of proceeding seems to be, to make an exact enumeration of all the phenomena; and, in the explanations relative to their connection, to dismiss every preconceived bias, as to the use and purpose of this mysterious portion of the universe. In this way, only, can we hope for a satisfactory solution of the questions, which still perplex us, notwithstanding all that has been observed and written on the subject. For this purpose the account, given by M. Burckhardt, and Professor Farrar, of the apparent separation of the coma from the nucleus, in this last comet, and such observations as were made by Dr. Prince, must be considered as valuable. The application, in a theoretical view, may not, at present, be perceived; but every thing of this sort should be collected and registered, and can hardly be too much in detail.

Of similar description are the observations of Dr. Herschell, on the comet of 1807, published in the Transactions of the Royal Society, 1808. *Aujourd'hui on lit mieux dans le ciel*, says Bailly, in reference to the telescope. In this sublime school, Herschell is among the best readers, and is deservedly placed on the first form. He observed the comet of 1807, from October 4, to February 21. Its brightness to the naked eye gave him hopes that he should find it of a different construction from any he had seen before, in which no solid body could be discovered with any of his telescopes. His attention was directed to such phenomena only as were likely to give information relative to the physical condition of the comet. In introducing the detail of his observations, he fixes the meaning of terms, the indefinite use of which had sometimes led to misapprehension.

The *nucleus*, according to his definition, is that part of the *head* which appears to be a condensed or solid body, and in which none of the very bright *coma* is included. When very small, no telescope that has not light and power to an eminent degree will shew it distinctly.

Head of the comet. With inferior telescopes, or if the magnifying power of a pretty good one be either much too high or too low, the very bright rays immediately contiguous to the *nucleus* will seem to belong to it, and form what may be called a head. "In reading what some authors say of the *head*, when they speak of the size of the comet, it is evident," says Dr. H. "that they take it for what is often called the *nucleus*. The truth is, that inferior telescopes, which cannot shew the real *nucleus*, will give a certain magnitude of the comet, which may be called its head; it includes all the very bright surrounding light; nor is the name of the *head* badly applied, if we keep it to this meaning." This state or aspect of the comet of 1807, Dr. H. found to be apparently of the size of *Jupiter*.

The *coma* is the nebulous appearance surrounding the head; in that comet it was, as observed by Dr. H. October 19, 6′ in diameter; on the 6th December 4′ 45″.

What is meant by the *tail* is sufficiently obvious.

Dr. Herschell gives in detail the appearances exhibited to his view at every observation, and concludes with the following interesting remarks.

" From the observations which are now before us, we may draw some inferences, which will be of considerable importance with regard to the information they give us, not only of the size of the comet, but also of the nature of its illumination.

" A visible, round, and well defined disk, shining in every part of it with equal brightness, elucidates two material circumstances; for since the nucleus of this comet, like the body of a planet, appeared in the shape of a disk, which was experimentally found to be a real one, we have good reason to believe that it consists of some condensed or solid body, the magnitude of which may be ascertained by calculation. For instance, we have seen, that its apparent diameter, the 19th of October, 6h. 20′ was not quite so large as that of the third satellite of Jupiter. In order, therefore, to have some idea of the real magnitude of our comet, we may admit that its diameter at the time of the observation was about 1″ which certainly cannot be far from truth. The diameter of the third satellite of Jupiter, however, is known to have a permanent disk, such as may at any convenient time be measured with all the accuracy that can be used; and when the result of such a measure has given us the diameter of this satellite, it may by calculation be brought to the distance from the earth at which, in my observation, it was compared with the diameter of the comet; and thus more accuracy, if it should be required, may be obtained. The following result of my calculation, however, appears to me quite sufficient for the purpose of general information. From the perihelion distance 0.647491, and the rest of the given elements of the comet, we find, that its distance from the ascending node on its orbit at the time of observation, was 73° 45′ 44″; and having also the earth's distance from the same node, and the inclination of the comet's orbit, we compute, by these data, the angle at the sun. Then, by calculating in the next place the radius vector of the comet, and having likewise the distance of the earth from the sun, we find by computation, that the distance of the comet from the earth at the time of observation was 1.169,192, the mean distance of the earth being 1. Now since the disk of the comet was observed to subtend an angle of 1″, which, brought to the mean distance of the earth, gives 1″.169, and since we also know that the earth's diameter, which according to Mr. Dalby, is 7913.2 miles,* subtends at the same distance an angle of 17″.2, we deduce, from these principles, the real diameter of the comet, which is 538 miles.

" Having thus investigated the magnitude of our comet, we may in the next place also apply calculation to its illumination. The observations relating to the light of the comet were made from the 4th of October to the 19th. In all which time the comet uniformly preserved the appearance of a planetary disk fully enlightened by the sun: it was every where equally bright, round, and well defined on its borders. Now as that part of the disk which was then visible to us could not possibly have a full illumination from the sun, I have calculated the phases of the comet for the 4th and for the 19th; the result of which is, that on the 4th, the illumination was 119° 45′ 9″, and that on the 19th, it had gradually increased to 124° 22′ 40″.†

" Both phases appear to me sufficiently defalcated to prove that the comet did not shine by light reflected from the sun only; for, had this been the case, the deficiency, I think, would have been perceived, notwithstanding the smallness of the object. Those

* See Philosophical Transactions for 1791, p. 239. Mr. Dalby gives the two semiaxes of the earth, from a mean of which the above diameter 7913.1682 is obtained.

† [Dr. H. refers to figures accompanying his paper representing the illumination. It was not thought necessary to copy them, as the numeral expression render his meaning sufficiently intelligible.]

who are acquainted with my experiments on small silver globules* will easily admit, that the same telescope which could show the spherical form of balls, that subtended only a few tenths of a second in diameter, would surely not have represented a cometary disk as circular, if it had been as deficient as are the figures which give the calculated appearances.

"If these remarks are well founded, we are authorized to conclude, that the body of the comet on its surface is self-luminous, from whatever cause this quality may be derived. The vivacity of the light of the comet also had a much greater resemblance to the radiance of the stars, than to the mild reflection of the sun's beams from the moon, which is an additional support of our former inference.

"The changes in the brightness of the small stars when they are successively immerged in the tail or coma of the comet, or cleared from them, prove evidently, that they are sufficiently dense to obstruct the free passage of star light. Indeed if the tail or coma were composed of particles that reflect the light of the sun, to make them visible, we ought rather to expect that the number of solid reflecting particles, required for this purpose, would entirely prevent our seeing any stars through them. But the brightness of the head, coma, and tail alone, will sufficiently account for the observed changes, if we admit that they shine not by reflection, but by their own

* Philosophical Transactions for 1805, p. 38, the 5th experiment.

radiance; for a faint object projected on a bright ground, or seen through it, will certainly appear somewhat fainter, although its rays should meet with no obstruction in coming to the eye. Now, as in this case we are sure of the bright interposition of the parts of the comet, but have no knowledge of floating particles, we ought certainly not to ascribe an effect to a hypothetical cause, when the existence of one, quite sufficient to explain the phenomena, is evident.

"If we admit that the observed full illumination of the disk of the comet cannot be accounted for from reflection, we may draw the same conclusion, with respect to the brightness of the head, coma, and tail, from the following consideration. The observation of the 2d of February mentions, that not only the head and coma were still very bright, but that also the faint remains of the tail were still visible; but the distance of the comet from the earth, at the time of observation, was nearly 240 millions of miles,* which proves, I think, that no light reflected from floating particles could possibly have reached the eye, without supposing the number, extent, and density of these particles far greater than what can be admitted.

"My last observation of the comet, on the 21st of February, gives additional support to what has been said; for at the time of this observation, the comet was almost 2.9 times the mean distance of the sun

* 239,894,939.

from the earth.* It was also nearly 2.7 from the sun.† What chance then could rays going to the comet from the sun, at such a distance, have to be seen after reflection, by an eye placed at more than 275 millions of miles‡ from the comet? and yet, the instant the comet made its appearance in the telescope, it struck the eye as a very conspicuous object.

" The immense tails also of some comets that have been observed, and even that of the present one, the tail of which, on the 18th of October, was expanded over a space of more than nine millions of miles,§ may be accounted for more satisfactorily, by admitting them to consist of radiant matter, such as, for instance, the *aurora borealis*, than when we, unnecessarily, ascribe their light to a reflection of the sun's illumination thrown upon vapours supposed to arise from the body of the comet.

" By the gradual increase of the distance of our comet, we have seen, that it assumed the resemblance of a nebula ; and it is certain, that had I met with it in one of my sweeps of the zones of the heavens, as it appeared on either of the days between the 6th of December and the 21st of February, it would have been put down in the list I have given of nebulæ. This remark cannot but raise a suspicion, that some

* The sun's mean distance being 1, that of the comet was 2.89797.

† The comet's distance from the sun was 2.683196.

‡ 275,077,889.

§ 9,160,542.

comets may have actually been seen under a nebulous form, and as such have been recorded in my catalogue; and were it not a task of many years' labour, I should undertake a review of all my nebulæ, in order to see whether any of them were wanting, or had changed their place; which certainly would be an investigation, that might lead to very interesting conclusions."*

The opinion which Dr. Herschell appears to have adopted, from his observations, that comets are self-luminous, is opposed to the supposition which has been most generally entertained, that the light which they present to us is altogether reflected. This is not the first intimation of his deviation from the generally received opinion on this subject. Of sixteen comets, which he had previously observed, he could distinguish the nucleus but of two. The rest appeared to him to be of a substance analogous to that of which their tails and coma are composed; and through the heads of some of them, we are informed, he could

* By an article in the London Courier of the 28th of October last, it appears that Dr. Herschell, in a paper lately read before the Royal Society, has retracted some of his former opinions respecting nebulæ. He had considered them as clusters of stars. He now, it is said, concludes them to be peculiar condensed matter, and supposes that they may constitute or become *comets*. If this account be correct, we seem to be returning to the Peripatetic doctrine; after the older system of Pythagoras, and of the Chaldeans, which considered comets as permanent bodies, had been revived, with seemingly convincing evidence, and appeared to be perfectly established.

perceive the stars with which they were in conjunction. La Place observes, that what we call the nucleus of comets is only the dense part of the nebulosity that surrounds them, and that it is penetrated, throughout, by the solar rays, which are reflected by its particles in every direction. He adds, that no phases can be perceived in them: and De Lametherie suggests a conjecture, that their whole mass is sometimes reduced to an aeriform state by the action of the sun. These opinions, supported as they are by names of great celebrity, it is thought proper to repeat; but, though entitled to consideration and respect, they will not, probably, be considered decisive. La Place has evidently not yet adopted any determinate scheme, relative to the constitution of comets, or even as to their motions; for he suggests an inquiry as to the hyperbolic orbits of some of them, and whether they may not travel from system to system. A vast field is before us, and a correct theory on the subject is probably reserved for remote posterity. This enjoyment, for such it must be, to every inquisitive mind, must depend on repeated, careful, and patient observation. Observation listens attentively to nature; experiment interrogates her. The first is open to all; the latter can be conveniently exercised but by a few. The subject under consideration is incapable of being decided by direct experiment. But it is observable, that in proportion as experimental philosophy has advanced, sounder theories and opinions, by just inference, arise, on topics apparently remote from its sphere, from connexions, which could not be anticipated. True knowledge of the constitution of the heavenly bodies must be derived from analogies to what we know of substances within our reach; and this connexion is an additional stimulous to the most extensive and laborious researches, into the constitution and relations of things.

The theory of gravitation and the laws of motion of the celestial bodies are but an extension of what is ascertained on our own planet. The same remark is applicable to the rainbow, which an ancient philosopher must have despaired of explaining. When electric phenomena became a general object of study, the identity of lightning with the electric fluid was placed beyond a doubt. Chemistry has of late years very much engaged the attention of the age, and has been attended with correspondent advancement. Perhaps it is reserved to this favourite science, from its singular combinations and its novel productions, to suggest the clue, which may relieve our views of comets, of the aurora borealis, and the meteoric stones, from some of their difficulties.

In the old maxim, said to be derived from Hermes, and which was countenanced by the sage Maclaurin, there is a great deal of truth, συμπαθη είναι τα άνα τοις κατω; *there is a correspondence between things above and things below;* but we should guard against an undue extension of the principle. It is certainly much preferable to the low adage of one of the ancients, *quæ supra nos, nihil ad nos,* which was probably intended for wit, and has been taken for wisdom.

La Place suggests a thought, derived from the modern doctrine of Caloric, which comes in aid of Mr. Oliver's supposition, that comets may be comfortable abodes, notwithstanding the great changes of condition which they undergo, from the prodigious excentricities of their orbits. In every change of state produced in a body by heat, it is now understood, that part of the heat employed becomes latent and insensible to the thermometer, but re-appears and becomes sensible, when the body returns to its former state. When a gas, contained in a flexible envelope, is dilated by increase of temperature, the thermometer is not affected by the portion of heat producing that effect; but this latent heat becomes sensible, when, by compressing the gas, it is restored to its primitive density. Thus if the nebulosity surrounding comets and their extensive tails be the result of the vaporisation of fluids, or of any substance at their surface, the cold thus produced must, he observes, temper the excessive heat arising from their proximity to the sun; and the condensation of those vaporised fluids, as the comet recedes from the sun, will repair, in part, the diminution of heat, which such elongation would otherwise produce.

The apprehensions, which were formerly entertained, of fatal or pernicious effects from comets, seem now to have given place to more comfortable and more rational views on the subject. So late, however, as 1773, great alarm was excited in France, from some suggestions either incautiously made by La Lande, or not correctly understood. Dr. Increase Mather, after the comet of 1682, published a treatise eminently calculated to excite similar apprehensions. He does not, indeed, lay much stress on the physical influence of comets. He considers them principally as—" preachers of divine wrath—heralds and messengers of evil tidings to the world."—His book is filled with a detail of disastrous occurrences succeeding the appearances of comets, from the earliest times; and reprehends those, who were disposed to regard such prognostications as groundless. He is particularly vehement against certain Jesuits, who had ventured to affirm, that there were some " *happy comets*," especially Vincentius Guinisius, who, it seems, had boldly published an oration *de felicitate Cometarum*, with peculiar reference to the comet of 1618. " I believe," says Dr. Mather, " there is not one good man in the world of his mind, as to that particular comet." The great majority, of every description, it is believed, would now concur with the other writer, of the same order, whom Dr. M. chastises, who hazarded the assertion, that the greater number of comets had not been attended with any signal calamity. *Plerosque cometas absque ulla calamitate fuisse* [redacted] assero.

Such conclusions, as were cherished by Dr. Mather, on this subject, were consonant to the prevailing bias of the age. They originated in a commendable motive; but we cannot avoid perceiving, that the collection of facts, adduced in support of the favourite position, was imperfect and unfair. The induction was altogether partial. A mild and salubrious compound may be made to yield an acrimonious extract; and it would, at all times, be easy to exhibit a terrific picture of human misery, if the benignant current of blessings, and the predominant balance of good, should be disregarded.

The propriety of these remarks might be exemplified from Dr. Mather's collection of disastrous events, compared with cotemporaneous occurrences of an opposite character: but it would, it is apprehended, be an unprofitable, and probably an unwelcome addition, to an article already unexpectedly extended, and might also be deemed invidious or unbecoming. It is, certainly, far from the intention of the writer, to disparage the reputation of a man, whose memory he reveres; nor would he be, willingly, instrumental in diminishing any serious impressions of a salutary tendency, which a contemplation of the great and unusual phenomena of nature may, at any time, excite. Dr. Winthrop, in his second lecture, has well expressed the moral uses of these "*exotic stars*," and his suggestions will not fail to have an influence on every considerate mind.

Whatever alarming apprehensions Dr. Mather's book might have made, at the time of its publication, they do not appear to have descended to this generation. Those mysterious strangers now receive a cordial welcome. Their gentle radiance has an air of clemency, and is viewed with calm complacence. No fears are entertained, of their impinging on any of the orbs of our system, or exercising a hurtful influence, by their approximation. M. Sejour, after the alarm in France, published an elaborate and ingenious treatise, proving, as he conceived, demonstratively, from an investigation of the motions and orbits of planets, that there could be no injurious interference. Dr. Winthrop has well explained their perfect adjustment to the system, from the great inclination of their orbits, and the diversity of their motions. La Place observes, that though from the inconsiderable quantity of matter which they contain, comets may be, and frequently are, affected in their motions by the planets, and particularly by Jupiter; yet there is no evidence of their disturbing even the satellites of Jupiter, though not unfrequently passing near to them. He concludes with a remark, particularly consoling to an astronomer, that the astronomical tables, which have been calculated and settled with so much laborious accuracy, are in no sort of danger of being affected by any disturbances of the planets or satellites, from the intervention of comets.—More general views, however, are sufficiently satisfactory on this head. Such admirable harmony and reciprocal adaptation, such marks of consummate wisdom and goodness, appear to every spectator, in objects with which we are familiar, that we readily cherish a persuasion, that the same characteristics are extended to the whole frame of the universe. Thus the sober medium is produced between disquietude and indifference. This repose of the imagination, however, should not induce a remission of our inquiries. In addition to their beneficial effect on the mind, by affording it innocent occupation and wholesome exercise, and by promoting that fairness and impartiality, so necessary in other investigations more immediately interesting to our present state and condition, it is certain that our veneration of the Infinite Deity will increase with a knowledge of his works. We shall cherish a grateful sense of his adorable benevolence, that has given us a place in one of his "many mansions," made us intelligent spectators of his fair creation, instruments and agents in the operations of beneficence, and the sensible recipients of his bounty.

Boston, Dec. 20, 1811.

THE END.