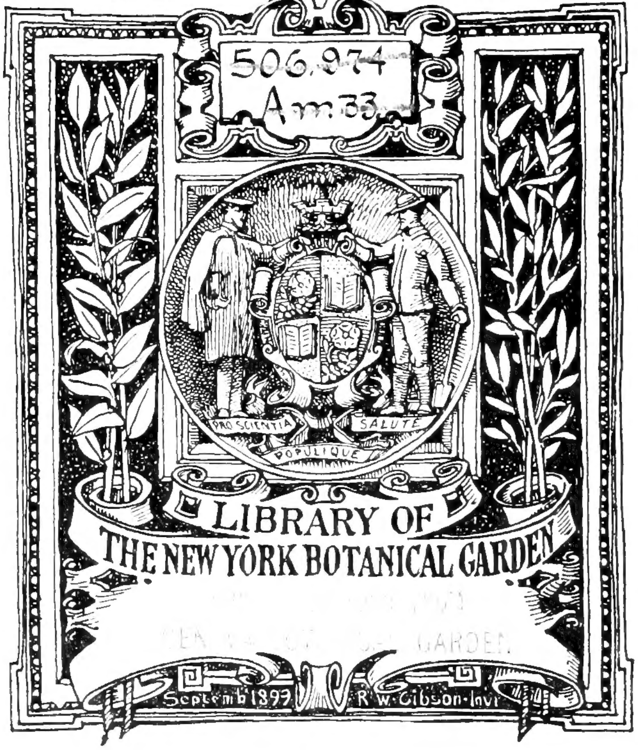

PRO SCIENTIA
SALUTE
POPULIQUE
Septemb 1897
R. W. Gibson. Invt

MEMOIRS

OF

THE AMERICAN ACADEMY

OF

ARTS AND SCIENCES.

MDCCLXXX.

CENTENNIAL VOLUME.

VOL. XI. — PART I.

CAMBRIDGE:
JOHN WILSON AND SON.
University Press.
1882.

[redacted]

MEMOIRS

OF

THE AMERICAN ACADEMY

OF

ARTS AND SCIENCES.

MDCCLXXX.

CENTENNIAL VOLUME.

VOL. XI.

CAMBRIDGE:
JOHN WILSON AND SON.
University Press.
1888.

CONTENTS.

Part I.

Part II.

MEMOIRS

OF

THE AMERICAN ACADEMY

OF

ARTS AND SCIENCES.

MDCCLXXX.

CENTENNIAL VOLUME.

VOL. XI. — PART I.

CAMBRIDGE:
JOHN WILSON AND SON.
University Press.
1882.

CONTENTS OF VOLUME XI., PART I.

THE
CENTENNIAL CELEBRATION
OF
THE ACADEMY.

At a meeting of the American Academy held Oct. 8, 1879, a Centennial Committee was appointed to deliberate on the best method of celebrating the hundredth anniversary of the foundation of the Academy. The following committee was appointed: —

Robert C. Winthrop, *Chairman.*

John A. Lowell.
Nathaniel Thayer.
B. E. Cotting.
Erastus B. Bigelow.
J. P. Cooke.
Robert Amory.
Asa Gray.
W. B. Rogers.
H. H. Hunnewell.
J. Ingersoll Bowditch.
Alexander Agassiz.
Theodore Lyman, *Secretary.*

The vacancy afterwards occasioned by the death of Mr. Bigelow was filled by the appointment of Mr. Edward Atkinson.

The Committee fixed on Wednesday, May 26, 1880, as the day for the celebration, and decided that the exercises should be in two parts, a public meeting at the Old South Church with an address by the President, Hon. C. F. Adams, and a reception at the hall of the Academy. Formal invitations were issued to corresponding Societies, to Foreign Honorary Members, and to other persons of distinction.

On the day appointed, at noon, the Committee received the Fellows and guests at the hall of the Academy in the Athenæum building. The company counted about three hundred gentlemen, of whom one hundred were Fellows.

Seventeen foreign academies were represented by delegates: —

The Literary and Historical Society of Quebec, by J. McPherson Le Moine, and George Stewart, Jr.

The Statistical Society of London, by EDWARD JARVIS, WILLIAM BARNES, and JOHN LANGTON.

The Cambridge Philosophical Society, by A. G. GREENHILL.

The Geographical Society of Paris, by ARNOLD GUYOT.

The Geological Society of Paris, by ECKLEY B. COXE.

The Royal Swedish Academy of Sciences, by JOHN ERICSSON.

The Imperial Academy of Sciences at St. Petersburg, by ASA GRAY.

The Astronomical Society of Leipsic, by E. C. PICKERING.

The new Zoölogical Society of Frankfort on the Main, by OSCAR FLINSCH.

The Holland Society of Sciences in Haarlem, by JAMES D. DANA and SIMON NEWCOMB.

The Entomological Society of Brussels, by H. A. HAGEN and S. H. SCUDDER.

The Society of Natural Sciences in Cherbourg, by ASA GRAY, ALEXANDER AGASSIZ, and W. G. FARLOW.

The Geographical Society of Bordeaux, by F. DE BOULANGER.

The Academy of Sciences at Bologna, by ALEXANDER AGASSIZ and HENRY O. MARCY.

The Academy of the Lynxes in Rome, by VINCENZO BOTTA and D. A. WELLS.

The Geological Survey of India at Calcutta, by W. T. BLANFORD.

The Naval Observatory at San Fernando, by JOHN N. MONTOJO.

The learned societies in the United States were represented by numerous delegates:

The American Philosophical Society, by J. SERGEANT PRICE, PLINY EARLE CHASE, and HENRY PHILLIPS, Junior.

The Academy of Natural Sciences at Philadelphia, by THOMAS MEEHAN, W. M. CANBY, ISAAC C. MARTINDALE, and JOHN H. REDFIELD.

The Connecticut Academy of Arts and Sciences, by C. S. LYMAN.

The New York Academy of Sciences, by OLIVER P. HUBBARD and THOMAS EGLESTON.

The Essex Institute of Salem, by D. B. HAGAR and ROBERT S. RANTOUL.

The Academy of Sciences at Davenport, Iowa, by C. C. PARRY.

The Albany (N. Y.) Institute, by JAMES HALL and HENRY A. HOMES.

The Massachusetts Historical Society, by CHARLES C. SMITH and SAMUEL A. GREEN.

The American Antiquarian Society, by DWIGHT FOSTER.

The New England Historic, Genealogical Society, by MARSHALL P. WILDER.

The Thayer School of Civil Engineering at Dartmouth College, by ROBERT FLETCHER.

The American Pharmaceutical Association, by S. A. D. SHEPPARD and F. H. MARKOE.

The American Oriental Society, by SAMUEL WELLS WILLIAMS.

Among the other guests present were: —

O. C. MARSH and T. W. GIBBS, of New Haven.

J. HAMMOND TRUMBULL of Hartford.

ALFRED M. MAYER, of Hoboken, New Jersey.

C. A. YOUNG, of Princeton, New Jersey.

NOAH PORTER, W. A. NORTON, and BENJAMIN SILLIMAN, of New Haven.

Charles S. Bradley, J. Lewis Diman, and
Zachariah Allen, of Providence.
Henry A. Rowland of Baltimore.
C. H. F. Peters of Clinton, New York.
Raphael Pumpelly of Newport, Rhode Island.
R. G. Hazard of Peacedale, Rhode Island.
Henry L. Abbot, U. S. A.
Albert N. Arnold of Pawtucket, Rhode Island.
Thomas Hill of Portland, Maine.

At one o'clock the company proceeded to the Old South Meeting House, where the Hon. Robert C. Winthrop, who had consented, on a few hours' notice, to deliver the chief address, presided. Around him, on the platform, sat Professor William B. Rogers, president of the Institute of Technology; the venerable Mark Hopkins of Williamstown; the Very Reverend the Dean of Chester, England; Joseph Lovering, the Vice-President, and other officers of the Academy.

The Rev. Dr. Mark Hopkins invoked the blessing of Divine Providence upon the occasion, and then followed the

ADDRESS BY THE HON. ROBERT C. WINTHROP.

We are here, ladies and gentlemen, to commemorate the hundredth anniversary of the American Academy of Arts and Sciences. The committee of arrangements, whose organ I have the honor to be, have selected for our public exercises this venerable meeting-house, in which not a few of those who founded our institution, a hundred years ago, were accustomed to assemble for the worship of God; and in which many more of them had often met, on most memorable occasions, to take counsel for the defence of American liberty. It is the meeting-house, too, in which the governors and legislatures of our Commonwealth, for a long succession of years, and until a somewhat recent period, have listened to their annual election sermon, on this very day of the year, — the last Wednesday of May. Having been providentially spared from the flames of the great Boston fire of 1872 — of the arrest of whose ravages in this direction it stands as a landmark and a monument, — I had almost said as a brand from the burning, — it has mainly owed its continued preservation to the pious and patriotic efforts of the ladies of our city and vicinity; and to them and their associates of our own sex we offer our grateful acknowledgments for the privilege of being here to-day.

But, my friends, this Old South meeting-house has an association for us, as an Academy of Arts and Sciences, nearer and dearer than any of those to which I have alluded. It was here, on this spot, in the old church edifice of this parish, that, with a punctuality and a despatch which seemed to prefigure, as it certainly characterized, his whole career, our great forerunner in the field of American Arts and Sciences, and I might add of American liberty, also, was baptized. Brought over here in a blanket from the home of his father and mother just across the street, on the very day of his birth, — Sunday, the 6th of January, old style, or, as we now count it, the 17th of January, 1706, — that infant child of a humble tallow-chandler received from the lips of the pastor of this Old South Church, not without the blessing of God invoked and vouchsafed — "non sine Diis animosus infans" — the name of BENJAMIN FRANKLIN. Where, where else, so appropriately could American Art and Science repair for the celebration of their own birth, their own small beginnings, their own infant lispings, as to the cradle and the christening font of our great Bostonian! If, indeed, my friends, we had a second day to spare for our celebration, it might well be occupied in an excursion to the birthplace and early home of another Massachusetts Benjamin, — Benjamin Thomson, Count Rumford, the great benefactor of this Academy and the founder of the Royal Institution in London, — such an excursion as Tyndall took pains to make a few years ago under the escort of Rumford's biographer, Dr. Ellis, in token of his reverence for the memory of the great American philosopher of light and heat. But we must content ourselves with a single day and a single birthplace.

We may not, however, forget that while the history of American Arts and Sciences may fairly begin with our Boston-born printer's apprentice, that history must turn to another city and another State for the opening pages of its earliest chapter. Old as we are, we cannot claim the distinction of being the oldest of American Scientific Associations, and we are rejoiced to recognize and to welcome among our guests to-day a distinguished delegation from our elder sister, the American Philosophical Society of Philadelphia, which was founded by Franklin not a great many years after he had run away, as a lad of seventeen, from his apprenticeship and indentures here, and had established himself in the City of Brotherly Love. That noble city has a heritage of historic glory which may well be the admiration, if not the envy, of all other American cities. Not only was it the scene of the first Continental Congress, of the immortal Declaration of Independence, and of the formation of the Constitution of the United States; — but it was the birthplace, also, of the first American public subscription library; of the first volunteer fire engine company; of the first volunteer militia regiment, of which Franklin was the colonel; of the first American agricultural society; of the first American Bible society; and, I believe I may safely add, of the earliest anti-slavery society in our land. But it is as the acknowledged birthplace of the first American philosophical society that we hail it especially on this occasion, and welcome the delegates from that city and from that society with an exceptional emphasis and fervor. We welcome, indeed, most heartily to this occasion every one of the delegates who have honored us by their presence from other cities and States, and from other institutions, American and foreign; from Washington, from New York and New Hampshire, from Connecticut and Iowa and California, from Italy and France and Russia, from Belgium and Holland and Denmark and Germany and Sweden, from the Dominion of Canada and from old England, and from wheresoever else beneath the sun they may have come to our festival; and we shall hope for an opportunity of expressing our acknowledgments to them all at a later hour of the day, if not now. But they will all pardon us, I am sure, for confining our first individual recognition, here and now, to the parent American Philosophical Society of Philadelphia.

That Society originated in a time of colonial peace and quietness. Our Academy had its origin while the war of independence was still in progress, while the principles of republican equality were on every tongue and in every heart, and when our honored founders would have been foremost in protesting against anything which looked like a recognition of hereditary rights or claims to consideration. Yet I cannot forget, not merely that the distinction of presiding on this occasion has been assigned to the oldest living descendant of our first president, James Bowdoin, but that it was to have been my privilege and pleasure, in a few moments, to present to you the oldest living descendant of him, who, more than any other one man, is to be remembered this day as the founder of our Academy, the illustrious John Adams. Having succeeded Governor Bowdoin as president of the Academy, and having himself been succeeded, after no very long interval, by his hardly less illustrious son, John Quincy Adams, the chair which they both filled is now occupied and adorned by a third scion of the same distinguished stock. Primo et secundo avulsis, "non deficit alter aureus;" or, if I may borrow a line from the translation of the Æneid, by his Excellency Governor Long, whose necessary absence we all regret, I may say, —

"The first torn off,
There lacks not still another branch of gold."

Having been our minister at London during a very critical period, and our commissioner at Geneva at the great arbitration, the Academy were proud to place at their head one so deservedly distinguished at home and abroad, and we relied upon him especially to-day to crown a faithful service of many years by pronouncing our centennial oration. But, my friends, I have a great disappointment to announce to you at this moment, and one to which it requires all the philosophy which may have been accumulated by this Academy in a whole century, individually or collectively, to be easily reconciled. Our excellent president, no longer on the sunny side of three-score years and ten, and with whose infirmities in this respect I have a right to feel a special sympathy, has found himself, within the last twenty-four hours only, so oppressed by the heat of the weather, by the responsibilities of this occasion, and by positive ill health, as to be absolutely unable to be with us. The loss is as irreparable as it was unexpected. It would be quite impossible for any one at a day's notice to prepare a worthy address for such an occasion as this. Our story would have been told by him amply, aptly, admirably. You would have had the detailed account of our original organization as an Academy, and of the excellent men who were foremost in its early proceedings. He would have done full justice to every one of them, except, perhaps, to his own venerated grandfather and father; and our grateful memories would have been sure to supply in that respect whatever his modesty might have omitted. All our other eminent presidents would have received their merited tribute at his hands. For, indeed, there has been a noble succession of admirable men in our chair, — BOWDOIN and the ADAMSES; HOLYOKE, the eminent physician and surgeon, who was permitted to round out a full century of life; NATHANIEL BOWDITCH, known as a young man upon all the seas by his *Navigator*, and afterward known to science throughout all lands by his translation of the *Mécanique Céleste* of La Place; good Dr. JAMES JACKSON, whom old Thomas Fuller might have had in mind and taken as a pattern in his portrait of the beloved physician: JOHN PICKERING, with his vocabularies and lexicons and orthography of the Indian languages of North America, — one of the chief founders of American Comparative Philology; JACOB BIGELOW, with his manifold and marvellous acquirements, his sterling common sense, his quick wit and abounding humor, and his consummate medical wisdom; and, lastly, our great botanist, ASA GRAY, of whom I dare not say, in his living presence, — which we all welcome, — what all of us know and appreciate without its being said by any one, — whose recent Lectures at Yale College, on "Natural Science and Religion," would alone be enough to secure for him the respect and gratitude of every Christian reader.

But it is not for me to attempt to do justice to these and other eminent presidents and fellows of our Academy by such undigested utterances. Their names, however, even if it be nothing but their names, must not, and shall not, be lost to our centennial commemoration.

Meantime, if we are deprived to-day of any protracted discourse upon the great objects of our Association, or upon the success with which those objects have been prosecuted during the hundred years which are now completed, we may at least point with satisfaction and pride to our published record. The elaborate and stately volumes of our proceedings and memoirs, which have succeeded each other to the number of nearly one for every three years of our existence, have furnished, and still furnish, abundant materials for all who may be inclined to pass a candid and deliberate judgment on our sayings and doings for a century. To them we confidently appeal. And let it not be forgotten, that the lack of pecuniary means, and not any lack of good will or good work or good matter, has prevented more frequent and more regular publications. With an adequate publication fund, such as we are now striving, — and by no means without success, — to establish, as a centennial tribute to the cause of science and art, no worthy laborer in that cause will longer be deprived of an opportunity to give the result of his researches to the world, and every successive year will have its regular and rightful volume. It is not prudent, however, for us to boast ourselves of to-morrow, while this centennial fund is but little more than half made up; and, even as to the past, we may well remember the warning of the wise man of Sacred Writ; "Let another praise thee, and not thine own mouth; a stranger, and not thine own lips."

The first President of our Academy, Governor Bowdoin, whose words I have an hereditary right to borrow and appropriate, — though I should hardly care to inherit a responsibility for some of his peculiar astronomical theories and speculations, — when he pronounced his inaugural discourse in 1780, looked forward distinctly to this very day and hour and occasion, and attempted to anticipate what would be said of the Academy by some American historian, some American Livy or Thucydides, as he said, at the close of a century. Let me read from his address, as printed at the time, and from the very copy which has come down to me as an heirloom, a few sentences as he delivered them on the 8th of November, 1780. After acknowledging most gratefully the influence of the Philadelphia Society and the paramount and pre-eminent influence of Harvard University, the mother of us all, in everything which pertained to the advancement of education and learning, and of the arts and sciences, — he proceeds thus: —

"'Rapt into future times,' and anticipating the history of our country, methinks I read in the admired pages of some American Livy or Thucydides to the following effect: —

"A century is now elapsed since the commencement of American independency.

What led to it, and the remarkable events of the war which preceded and followed it, have been already related in the course of this history.

"It was not to be expected that our ancestors, involved as they were in a civil war, could give any attention to literature and the sciences; but, superior to their distresses, and animated by the generous principles which liberty and independency inspire, they instituted the excellent society called 'The American Academy of Arts and Sciences.'

"This society formed itself on the plan of the philosophical societies in Europe, adopting such rules and principles of conduct as were best suited to answer the end of its institution. Among others they laid it down as a fundamental principle, that as true physics must be founded on experiments, so all their inquiries should, as far as possible, be carried on and directed by them. This method was strongly recommended by Sir Francis Bacon, 'a genius born to embrace the whole compass of science, and justly styled the first great reformer of philosophy.' It was adopted by succeeding philosophers, and peculiarly by the immortal Newton, whose system of philosophy, founded on the laws of nature, will for that reason be as durable as nature itself.

"Taking these great characters for their guide, and influenced by their illustrious example, they proceeded on fact and observation, and did not admit of any reasonings or deductions but such as clearly resulted from them. This has been the uniform practice of the society, whose members from time to time, having been chosen from men of every country, from every class and profession, without any other distinction than was dictated by the dignity of their characters, by their morality, good sense and professional abilities, — we find in the printed transactions of the society the best compositions on every subject within the line of their department. We find in those transactions new facts, new observations and discoveries; or old ones placed in a new light, and new deductions made from them.

"They have particularly attended to such subjects as respected the growth, population, and improvement of their country: in which they have so happily succeeded that we now see agriculture, manufactures, navigation and commerce in a high degree of cultivation; and all of them making swift advances in improvement as population increases. In short they have, agreeably to the declared end of their institution, 'cultivated every art and science which might tend to advance the interest and honor of their country, the dignity and happiness of a free, independent, and virtuous people.'"

All these were the words of our first President a hundred years ago. This was his "prophetic history," which he trusted would be realized by fact and be recorded by some future American Livy or Thucydides.

But what would he have said had it been vouchsafed to him really to penetrate that veil of the future which he contemplated, and to foresee even ever so small a part of that which has actually occurred, and been practically accomplished, in the arts and sciences to which this Academy has been dedicated. How would he and his fellow-founders of our institution have exulted, could they have known something of the stupendous discoveries in the heavens above and in the earth beneath and in the waters under the earth, which were to mark the century now ended so peculiarly as their own century! What words could have measured their amazement at the wonderful instruments which are now piercing the skies, and at the marvellous engines which are now tramping and thundering over land and sea, scooping out canals like that of Suez, or, it may be, of Darien or Nicaragua, as they go; or tunnelling mountains, like Mount Cenis or St. Gothard, or, it may be, Mont Blanc itself, to which our own little Hoosac is but a molehill! What would they have said, could they have caught the click of an ocean, or even of a land, telegraph; or listened to some words of their own bottled up for a century, and coming out fresh and articulate, from the lips of a telephone or phonograph! What delight they would have enjoyed could they have witnessed the working even of any of the myriad of lesser and simpler inventions and implements of practical art, which are ministering to the daily and hourly convenience and comfort of common life! And what ecstasy would have mingled with their bewilderment, as they reflected that, by building up their little local Academy, they might claim some humble part in fostering and furthering the great scientific movement which had pervaded the world, and might thus themselves be entitled to some humble share in the glory! What satisfaction they would have enjoyed in knowing, too, that our foreign honorary membership would be so highly appreciated by the select few on whom it has been conferred, and in seeing upon our roll such names as Helmholtz and Kirchhoff, as Sir William Thomson and Sir Joseph Hooker, as Owen and Max Müller, as Carlyle and Mignet, and Dean Stanley and Gladstone, and Ruskin and Tennyson, standing side by side with those of our own Peirce and Gray, and Rogers and Emerson, and Longfellow and Whittier, and Holmes and Bancroft, and Hopkins and Woolsey, and Dana and Porter!

Could the founders of this Academy even now look down from the skies, as we may hope they may be permitted to look down to-day, upon our own little State of Massachusetts and our own little city of Boston, with what rapture would they behold, encircling this Academy as their original nucleus, their primal nebula, if I may so speak, — a Natural History Society, with its manifold and growing collections and cabinets; a Technological Institute, with its admirable curriculum of scientific education; a splendid Museum of the Fine Arts; an Observatory, with its comet-seekers and transit instruments, and with its noble refractor; the Lawrence Scientific School; the Chemical Laboratory of Professor Cooke; the Garden and Herbarium of our great botanist, Dr. Gray; the magnificent Agassiz Museum of Comparative Zoology, where an accomplished son is so nobly carrying on the cherished work of his ever-honored and lamented father, and, close at its side, the Peabody Museum of Archæology and Ethnology; and all our thriving associations of History and Literature and Music, of Horticulture and Agriculture; and, better than all, the hosts of busy and devoted students in these and other institutions, who are engaged, day by day and night by night, in searching out the mysteries of Nature, and extorting from her so many of the secrets which have been hid from all human eyes and all human conceptions from the foundation of the world!

They would be convinced that there was, indeed, such a process as Evolution, though I think they would be content, as some of their descendants still are, to call it by the good old-fashioned name of *development.* They would certainly concur in the idea that their little Academy had furnished, or fallen upon, a plentiful supply of protoplasm, though I have great faith that they would cling tenaciously to the simpler and more euphonious word — *germ.* At all events, they would be heard exclaiming with one accord, in the sublime words with which our first President concluded his inaugural discourse a hundred years ago, "Great and marvellous are thy works, Lord God Almighty, in wisdom hast thou made them all!"

And with these words I, too, must be allowed to close this attempt — from which I would so gladly have been excused — to fill a gap which was not dreamed of until a late hour of yesterday, and to deliver a centennial oration at less than twenty-four hours' notice. If I have thus exhibited my reverence for the memory of our first President, and my loyalty to the Academy in its hour of need, and if I have rendered the lamented absence of my honored friend, Mr. Adams, less painful to himself as well as to you, I shall be more than rewarded for the effort. I should be sorry, however, to be involved in such an emergency again, at least before the expiration of another full hundred years!

Brief addresses were then made as follows: —

BY DR. OLIVER WENDELL HOLMES.

I feel, he said, as I felt some twenty or thirty years ago, when I was caught on the midnight New York train in a heavy snow storm between Framingham and Natick. All night we see-sawed back and forward between those two towns. We naturally became somewhat hungry, and some of us, perhaps, a little thirsty. Search was made for provender, and one lady produced a bag of crackers, and one gentleman a small flask containing a fluid — it was cold, I remember, and I think it must have been cold tea; but whatever it was, it was very welcome, and they dispensed it in very small quantities. In place of the supper which we expected, that was the fare we got. Now, I did not come prepared with anything for an assembly like this. I expected to be called up at the table of the Academy, after the gastric exercises had put the audience in a pleasant state of mind, and there to read a few verses to which I had been able to devote but a very little time. To read them to an audience like this is somewhat trying to my sensibilities, but I will trust implicitly to its good nature.

As a basis for my theme I took up the first volume of the records of the Academy and ran over a list of papers to see what the members were thinking and talking about in those times. I found that Manasseh Cutler wrote on a transit of Mercury, in addition to his able botanical article, that President Willard shed his light in an account of a recent eclipse, that Benjamin West — not the great painter, but perhaps a great mathematician — gave some rules about the extraction of roots, that Bowdoin contributed an elaborate article on an orb which surrounds the whole visible material system, that Williams wrote on the darkness of May 19, 1780, another member on the effects of lightning on a rock in Gloucester, and that many others discussed articles of a kindred nature. The result of this search furnishes the argument of these verses.

Sire, son and grandson; so the century glides;
  Three lives, three strides, three footprints in the sand;
Silent as midnight's falling meteor slides
  Into the stillness of the far-off land;
  How dim the space its little arc has spanned!

See on this opening page the names renowned
  Tombed in these records on our dusty shelves,
Scarce on the scroll of living memory found,
  Save where the wan-eyed antiquarian delves;
  Shadows they seem; ah, what are we ourselves?

Pale ghosts of Bowdoin, Winthrop, Willard, West,
  Sages of busy brain and wrinkled brow,
Searchers of Nature's secrets unconfessed,
  Asking of all things Whence and Why and How —
  What problems meet your larger vision now?

Has Gannett tracked the wild Aurora's path?
Has Bowdoin found his all-surrounding sphere?
What question puzzles ciphering Philomath?
Could Williams make the hidden causes clear
Of the Dark Day that filled the land with fear?

Dear ancient schoolboys! Nature taught to them
The simple lessons of the star and flower,
Showed them strange sights; how on a single stem—
Admire the marvels of Creative Power!—
Twin apples grew, one sweet, the other sour;

How from the hilltop where our eyes behold
In even ranks the plumed and bannered maize
Range its long columns, in the days of old
The live volcano shot its angry blaze,—
Dead since the showers of Noah's watery days;

How when the lightning split the mighty rock,
The spreading fury of the shaft was spent;
How the young scion joined the alien stock,
And when and where the homeless swallows went
To pass the winter of their discontent.

Scant were the gleanings in those years of dearth;
No Cuvier yet had clothed the fossil bones
That slumbered, waiting for their second birth;
No Lyell read the legend of the stones;
Science still pointed to her empty thrones.

Dreaming of orbs to eyes of earth unknown,
Herschel looked heavenwards in the starlight pale;
Lost in those awful depths he trod alone.
Laplace stood mute before the lifted veil;
While home-bred Humboldt trimmed his toy-ship's sail.

No mortal feet these loftier heights had gained
Whence the wide realms of Nature we descry;
In vain their eyes our longing fathers strained
To scan with wondering gaze the summits high
That far beneath their children's footpaths lie.

Smile at their first small ventures as we may,
  The schoolboy's copy shapes the scholar's hand,
Their grateful memory fills our hearts to-day:
  Brave, hopeful, wise, this bower of peace they planned,
  While war's dread ploughshare scarred the suffering land.

Child of our children's children yet unborn,
  When on this yellow page you turn your eyes,
Where the brief record of this Mayday morn
  In phrase antique and faded letters lies,
  How vague, how pale, our flitting ghosts will rise!

Yet in our veins the blood ran warm and red,
  For us the fields were green, the skies were blue,
Though from our dust the spirit long has fled,
  We lived, we loved, we toiled, we dreamed like you,
  Smiled at our sires and thought how much we knew.

Oh might our spirits for one hour return,
  When the next century rounds its hundredth ring,
All the strange secrets it shall teach to learn,
  To hear the larger truths its years shall bring,
  Its wiser sages talk, its sweeter minstrels sing!

BY PROFESSOR ASA GRAY.

Mr. Chairman: — Although called upon in another capacity, allow me, first of all, to acquit myself of a commission. The Imperial Academy of Sciences of St. Petersburg has instructed me to appear as its delegate upon this occasion, and has charged me to present this document, conveying the formal congratulations of its president, vice-president, perpetual secretary, and the principal resident academicians, attested by their signatures. It speaks of the services which our society has rendered to science and learning during the past century as a warrant for high expectations in the future. You will excuse me from reading the Latin document. The Russian pronunciation of Latin is so different from the American that I might not be readily understood.

Let this serve as a specimen of the various addresses of congratulation of a similar character from learned societies of Europe which our Academy has received.

And now, Mr. Chairman, your call upon me as the representative of the past — not exactly as the veteran who lags superfluous on the stage, because you have occasion to use me as a link between the present and the olden time, and so I am not quite superfluous — is certainly one which brings up serious thought. It does appear that, since the death of my venerable predecessor, Dr. Bigelow, I am, *ex officio*, the solitary link connecting the Academy of to-day with the worthies who have presided over it in the nearer past, and in the old time before them. It brings to mind the fact that when I began to take part in the Academy's business and publications (I had the honor of an election into it before I came to Cambridge and to Massachusetts, thirty-eight years ago) I used to look forward to this anniversary as an epoch of uncommon interest, and to hope, rather than to expect, that I might be here to see it. It seemed a long way off, and even the retrospect now, over the full third of a century, is a good deal to contemplate, covering, as it does, a large portion of one's lifetime.

Still, I would have my associates here to remember, and our guests to understand, that I bear the title of venerable only by brevet, and by the accident of position. There are surviving fellows, still flourishing in full vigor, still among our most active members, — such as our Vice-president and our renowned mathematician, and our poet, — who had made their mark in this Academy and in the world before I became their associate.

They, and a few others of our present number, who had the advantage, denied to me, of being born, or at least educated, within sight of the State-house dome, — they can retrace the line of recollection farther, and speak from personal knowledge of our illustrious President, Bowditch, whom I never saw in the flesh, but upon whose benignant features, looking down upon us from the marble bust in our hall, I have often gazed with reverent admiration. With him the modern history, the truly scientific era of our Academy, began. He secured for it a status and an importance which it never had before, and we hope has never lost. Even if I could personally speak of him, no words of mine could enhance our abiding sense of the value of his services to us, and our veneration for his memory.

The beloved physician who succeeded him held office for a single year, long enough to grace the presidential roll with the name of Jackson, *facile princeps* of the medical profession.

When I came into the Academy the Hon. John Pickering was its President. Under him Dr. Holmes and myself served for some time as secretaries. As he died in office, in the year 1846, my acquaintance with him was short. It is only the older of the fellows here present who will have known this dignified, kindly, scholarly, and learned man.

Of his successor, Dr. Bigelow, who so ably and acceptably presided over the Academy for the next seventeen years, — adorning this as he did all the very diverse stations and vocations to which he was called; who was for sixty-seven years a fellow in this society; who, though he did not in longevity quite equal our sole centenarian, Dr. Holyoke, yet came near to it; who has so recently laid aside the burden of the flesh, — the reverent mention of his name upon this occasion is all that is needed from me. Even if our younger members have hardly seen or known him, — so long did he survive in retirement, — the eulogy placed only a year ago upon our printed records is still fresh.

Allow me here to bring up to your memory a contemporary name, that of a member who served the Academy long and well, who was one of its wisest counsellors and most devoted sons; whose scientific genius, always of a practical bent, was the parent of very important inventions; who in his earliest will, made when as a young man he first crossed the ocean, bequeathed the whole of the small property he had then accumulated to Harvard College, "for the promotion of a knowledge of mechanical philosophy"; who, living to acquire an ampler but still modest property, besides providing for this early intent, bequeathed to this Academy a share of his estate which ranks him as its largest pecuniary benefactor, — larger even than Rumford, if you count his trust as a gift to the Academy; who held for years the office of Vice-president, and who should have been President. A temporary unpopularity at a critical juncture prevented this, else the roll would have borne the name of Daniel Treadwell. I understand that the biographical tribute which this Academy owes to his memory, and which has been so long delayed, is now about to be paid, in connection with this centennial celebration. Since it was my fate to occupy the place which should have been his, I trust I may be permitted to associate him with those who have more fully presided over this society, in the sentiment which I would now offer: —

"The memory of the deceased Presidents and distinguished fellows of the American Academy who, each in his course, have in their day and generation worthily served this society, their country, and the world; may their successors in the second century emulate their example, and build as well, or better, if they can, upon this centennial foundation."

A century suffices merely to lay the foundations of an institution for investigation. Let our successors carry up the superstructure, not as expecting to complete it, but to raise it higher. The foundations of the temple of Science are laid upon the earth, on "the solid ground of Nature," to which "trusts the mind which builds for aye." But it is to rise above physical nature, and its topmost stone is to be laid in the highest heavens.

The Very Reverend JOHN S. HOWSON, Dean of Chester (England), was then introduced, and responded in these words: It was pleasant to come within the circle of so many noble interests. Americans had made him almost forget that the Atlantic separated him from home. He was slightly surprised at the American interest in English home politics, and at the disparaging manner in which they discuss their own public men. But he was deeply pleased with the modest endeavors, made in so many directions, of recording our past in order to make it available for future uses. The scholarships of Johns Hopkins University, the Library of Congress, and the rooms of the Historical Society at Philadelphia, to name but slight instances, had impressed him profoundly. For the candid study of the past and present was a guarantee of a safe future. An occasion like the present, it seemed to him, was rich in pathos and rich in poetry. He paid a delicate compliment to Mr. Winthrop, who knew so well that, after all, the values of imagination were not the least in this world. In conclusion, the Dean pointed out that all these treasures of mind, of history, and of material good placed upon this country a great responsibility; but he was ready to believe that there would be no fatal shortcomings. He had full faith in the future of America.

Professor W. B. Rogers said that, having been suddenly called upon to take part in the services of this hour, he could only give expression to such thoughts as suggested themselves at the moment.

He spoke of the seeming connection, in the history of communities, between great intellectual activity and extraordinary emotional excitement from political or other causes, as illustrated by the establishment of this Academy, the Sister Society of Philadelphia, the Royal Society of London, and other kindred associations, not forgetting our own Institute of Technology, in times of war and civil commotion.

He concluded with remarks on the wide scope of the studies encouraged by such societies, embracing, in the words of Bacon, "the studies that are for delight, for ornament and for ability," and maintained that in an enlarged view every intellectual pursuit has a far-reaching utility, each department of knowledge being allied with every other department, as in the boundless heavens each star whether small or great is a giver as well as a receiver of light, in relation to every other star.

At the close of the exercises in the church, the Fellows of the Academy and their guests proceeded to their rooms at the Athenæum building, where a collation was served, after which there were speeches by representatives of other societies. The Hon. Robert C. Winthrop presided, and in calling the company to order spoke as follows: —

Brothers of the Academy, Delegates from Kindred Associations at Home and Abroad, and Invited Guests: — The Committee of Arrangements have assigned to me the delicate and difficult task of conducting these closing ceremonies of our Centennial Festival. I am deeply conscious how rash it was in me — albeit not often accused of rashness — to accept such a responsibility. But repentance, as always, comes too late; and I know well that, after all which has occurred this morning, I can rely on your indulgence for any shortcomings in the discharge of a duty which might well have been laid on younger shoulders.

Let me not speak of ceremonies, however. The ceremonies and formal utterances of this occasion are happily over, and nothing remains for us but the brief and spontaneous interchange of such expressions of mutual congratulation and good-fellowship as belong to the afterpiece of such a commemoration. We look for no long or elaborate speeches from any one; and certainly you will expect none from me after the strain to which I have been so unexpectedly subjected at the Old South.

The most that I can do is to welcome again to our Centennial Festival the guests and delegates who have honored us by their presence, and I now once more, in the name of the Committee of Arrangements and in behalf of the whole Academy, bid them, one and all, heartily welcome to our board.

Nor must I fail to express, in a single word, our grateful acknowledgments to all the kindred Associations in foreign lands, and in other parts of our own land near and remote, which have sent us their greetings and congratulations, either by delegates or by formal responses to our invitation. Welcome to all who are present, and thanks to all who have remembered us! Success and gratitude and honor to the votaries of Art and Science throughout the world!

Mr. Winthrop called first for a response from the American Philosophical Society of Philadelphia. Mr. PHILLIPS, one of its delegates, presented, in a few words, its congratulations upon the past of the Academy and its best hopes for the future that awaited it. Mr. PRICE, another delegate, followed, expressing his thanks for the kindness that had been shown his brother delegate and himself, and then read the following address, written by FREDERICK FRALEY, LL.D., President of the society:—

It is with great pleasure that I reply to this call. As the elder sister of the Academy, the American Philosophical Society may well rejoice on the occasion that brings us together. While the society that I have the honor to represent dates its organization from 1743, its corporate existence was only a few weeks earlier than that of your association. Both were established by the patriotic men who shared in our revolutionary history, and both were made corporations while the din of arms and the uncertainty of battles occupied public attention. I have looked over your list of corporators and early members, and there I find many names which were the common property of Massachusetts and Pennsylvania, that even in those early days took the broad and comprehensive name of American. These two societies, starting under what might seem unpromising beginnings, soon won their way to places in literary and scientific repute, and after the lapse of more than a century hold their honors with undiminished lustre. The corporators of your Academy begin with Adams and end with Winthrop; and the names between, glorious in memories, have their present representatives not only in the Academy, but also wherever the Old Bay State needs a man to speak for her. So, too, of Pennsylvania; the golden roll of the American Philosophical Society bears, amid the new blood that has gradually been injected into its veins, the names of the descendants of the fathers, who manifest the same love for science and the same patriotism that fired their ancestors.

But turning from these pleasant memories, and taking a brief survey of the century, what abundant causes have we for felicitation! Some of us can look back over three-fourths of the time with all the vivid realizations of its great events and discoveries. To them, all that is past seems as of yesterday, so rapidly has the world moved in the present century. We have made immense gains in the knowledge of and the control of the material world, and in great additions to personal comfort and enjoyment; but have we to anything like the same extent improved our knowledge of our moral and intellectual nature? A few days ago I read the preface to the first volume of the Memoirs of your Academy; and the noble words and sound maxims with which it sets forth the objects and aims of the institution are like "apples of gold in pictures of silver." It struck me, while so reading, that truth was really eternal, and that science, with all her glories, could never be more than the handmaiden and servant of truth.

But, Mr. President, shall we not rejoice also in the influence of the example of our venerable associations? It is unnecessary for us to claim much of that influence beyond the limits of our own country. Here and around us to-day are some evidences, at least, of that influence. In the present broad expanse of our country, and in every State and Territory, we find associations, under various names, established for the promotion of science and useful knowledge, showing truly that your motto, "Sub libertate florent," was chosen with prophetic wisdom, for science may well say "Where liberty dwells there is my country."

In a celebration like this I must be short and merciful. I may be pardoned for dilating on the virtues and worth of the elderly maidens whose birthdays we may be said now to be celebrating, for they are almost twin sisters, and they have never since 1780 changed their names, although they have had many lovers. Such a persistence in virtue has had, and I hope will continue to have, its reward. Possibly one of them, and perhaps both, before the end of another century may be tempted to matrimony by some cunning evolutionists; but you and I, Mr. President, as guardians of these old vestals, must, wherever we may be, forbid the banns. And so crowned with the glorious memories of their past history, and being continually renewed by the adoption as their children of all who, of every kind, sex, tongue, and people, can give the shibboleth for admission, may they endure, from century to century, as monuments of the wisdom of our patriotic fathers and as the strongholds of truth and knowledge.

President ELIOT was called upon to respond for "Harvard University." He said: —

Mr. Chairman and Gentlemen: — It is with great diffidence that I obey your call when I see about me so many of the teachers of the university, older than I am, teachers of mine, men who might reply to this sentiment much better than I can. But I am sure that we all rejoice that, for a hundred years past, Harvard University and this Academy have worked together for common ends with the utmost harmony and with mutual benefit. The urgent desire immediately to impart knowledge once won is, it seems to me, one of the most delightful attributes of modern science. Whenever a scientific man wins a little new truth he must run somewhither to impart it, and, under the present organization of scientific and literary society, he inevitably goes to a body like this, to an Academy; so the rolls of this Academy bear the names of all the eminent investigators and scholars of the adjacent college. They come here for sympathy, for support, and to gratify this necessity of the scientific nature to give out what it has acquired. But when we look back, as we did in listening to the interesting address of the chairman this morning, and bring before our minds the situation of the men who a hundred years ago founded this Academy, do we not learn a lesson of profound humility? How meagre were their resources, how poor they were, but how gallant their spirit, and what seed they sowed! Mr. Chairman, with all the wealth at our command, with the mighty powers which are newly subject to us, can we hope to surpass, or even equal, the spirit of our forefathers? Nature has spoken to us as she never did to them; but we can only pray that our hearts and brains may be strong enough to fulfil our greater trust as well as they fulfilled theirs.

Professor BOTTA responded for the Accademia dei Lincei.

I regret that, owing to the absence of my colleagues, the duty of responding for the Academy de' Lincei devolves upon me. I had hoped that my distinguished associates, Professor Dana and the Hon. Mr. Wells, would be here on the present occasion, either of whom would have fulfilled that office more acceptably; and when the Secretary informed me, this morning, that I would be called upon, I begged to be excused, as I cannot but find it difficult to extemporize in a foreign language. It is true that he kindly gave me the choice of speaking in Italian; but, although you would all doubtless understand me if I spoke in my native tongue, yet you may perhaps prefer to hear my broken English.

So I bring you the congratulations and the good wishes of one of the oldest Academies of the world. Italy, as you know, is the mother of all scientific academies. She was the first country of modern Europe to establish those institutions, and it was through them that she kept alive, not only the spirit of intellectual progress, but also the spirit of liberty, through so many ages of despotism. In the sixteenth and seventeenth centuries almost every city of the Peninsula had its Academy, and chief among them was the Accademia de' Lincei, founded by Prince Frederick Cesi, in 1603, in the city of Rome, where the establishment of an institution which had for its object the investigation of the secrets of nature was beset with peculiar difficulties. Prince Cesi took the Lynx, remarkable for its keenness of vision, as the symbol of the Academy, and hence its name, the Lincei.

It is from this venerable institution that I come, a messenger of sympathy and friendship, to the American Academy of Arts and Sciences on the centennial anniversary of its birth. We are almost two centuries older than you, and for you we feel all the sympathy that old age feels for youth. In a few years we shall celebrate our third centennial, and I am charged to invite you all to join with us on that occasion. It will take place in about a quarter of a century, and I promise that you will be received with the hospitality and the reverence that will be due to you at that time.

Of the Academy of the Lincei and its illustrious members, both in the past and present, it is unnecessary for me to speak. I will only mention one name, that you all revere; that of the father of modern science, and of the true scientific method,—Galileo Galilei. He not only founded the method of induction in scientific research, but he invented many instruments by which science has continued to advance to this day; and the Accademia de' Lincei is entitled to the gratitude of all scientists, if only for the illustrious name of this great philosopher, the greatest of its members.

It may be of some interest to add that as soon as the Italian government took possession of Rome it made the Lincei the object of its especial patronage, under which it became the national Academy; and it is now to Italy what the Institute has been, and is still, to France. Its original departments were extended, and new ones added, in order to bring it up to the requirements of modern thought. It was at once endowed with an annual subsidy from the treasury, and two years since, on his accession to the throne, King Humbert, from his private purse, founded several prizes to be awarded by the Lincei for the best works on scientific subjects. For its renewed vitality and enlightened activity the Academy is particularly indebted to its President, Quintino Sella, whose high qualifications as a statesman are only equalled by his scientific attainments.

The sentiments which I have already expressed on behalf of the Academy which I have the honor to represent at this festival, I ask your permission now to repeat, in reading to you the message of the Lincei, written neither in English nor in Italian, but in Latin, the universal language of scientific men.

Q. B. F. S.
ACADEMIAE BOSTONIANAE ARTIVM ET SCIENTIARVM
VII. KAL. JVN. MDCCCLXXX
SOLLEMNIA SAECVLARIA CELEBRANTI
PIE GRATVLATVR OMNIA FAVSTA RITE PRECATVR
SODALESQVE SVOS
JACOBVM DANA VINCENTIVM BOTTA
VOTORVM INTERPRETES DESIGNAT RENVNTIAT
REGIA LYNCEORVM ACADEMIA
DATVM ROMAE EX AED. CAPITOLINIS NON. MART.
ANNO A SOCIETATE INSTITVTA CCLXXVII

Quintinus Sella
LYNCEORVM PRINCEPS

Dominicus Carutti } *Ab Actis*
Petrus Blaserna }

Mr. Greenhill, of Emanuel, Cambridge, was called upon to respond for the Cambridge (England) Philosophical Society. He said: —

Mr. Chairman and Gentlemen: — I beg to convey to you the thanks of the Cambridge Philosophical Society for the honor which is conferred upon me, and I beg, on my own behalf, to express my thanks for the very hearty welcome I have received during my visit to this country. I was requested, on behalf of the University, to express regrets that she was not able to send out a professor; but, in full term time, it was difficult to spare one. I feel sure that, had Professor Maxwell lived, he would have seized this opportunity to visit this country and see those in whose researches and in whose work he took so much interest. We are proud of the early history of this country, and particularly proud of numbering Mr. Harvard among our graduates. I feel, indeed, that our chief title to fame is to have sent forth into the world the founder of the University in this country, which bids fair, in the number of its students, in the endowment of study, and in the scope of its influence, to rival the parent institution in England. In four years' time, in 1884, we hope to celebrate the tri-centennial of the founding of Emanuel College, and we shall be pleased to give many of you as warm a welcome there as I have received here.

President PORTER, of Yale College, was the next speaker. He said: —

The duties prescribed to me by the Chair are very simple, and they can be discharged by a very short speech. I have simply to express the good will I feel toward this and similar institutions of this country. In behalf of my associates and of myself, I certainly can very heartily express this good will. I have been interested more than I anticipated in the exercises of to-day. They have vividly brought to my mind the fact of which I have often thought, but of which, as it seems to me, many are too little mindful; namely, that a century ago Philadelphia and Boston were the literary and scientific lights of this country. It was then that Dr. Franklin, as you, Mr. Chairman, have so happily shown, was a sort of circulating medium between the two, going to and fro, like a weaver's shuttle, and binding them together by manifold threads of scientific knowledge and good-fellowship. And how did he go from Boston to Philadelphia? Why, on horseback, on that dusty and gravelly road, which, if any man has ever tried, he will never care to try again, along the northern shore of Long Island Sound. In making this journey he uniformly spent the night at a town now called Clinton, in Connecticut. It was formerly called Killingworth, but was originally Kenilworth, after the Kenilworth of Warwickshire, from which so many of our ancestors came. And as he came near the Kenilworth or Clinton green his horse was always sure to turn a very square and abrupt corner, making for the house of a Rev. Jared Eliot, who was the pastor of this town of Kenilworth. This Rev. Jared Eliot I speak of as representing a great many country clergymen all over New England, who had the true scientific spirit, and who nurtured that spirit in their own hearts, and diffused it in the communities in which they lived. And I will remind you that all over New England there was an active scientific spirit ready to receive new truths of every kind; that of electricity for instance. And let me mention, for Dr. Holmes's special edification, that in Litchfield County, Conn., a very eminent clergyman, living on one of the highest hills in the county, took it into his head, very early in the history of the lightning-rod, to have one attached to his own house. Upon this one of his parishioners said, and the parishioners were generally pretty keen, as well as the clergymen: "If I believed in your doctrines I should just as lief have one of those things tied to my back as not." Difficult as it may be for some of us to believe it, religion and science, Calvinism and liberality, beautifully mingled together in those good old days a hundred years ago. I think we should give more credit than we do to the early scientific spirit of the New England people, represented as they were by the New England clergy. We ought to do more honor than we are apt to do to that universal spirit which, from these New England States, spread itself through the country; which sent their sons into the field of thought, which inspired them to found colleges, and to support institutions of learning, and prepared them to receive new truth, from whatever source it came. This true scientific spirit created New England, and will sustain New England in the future. When I was in Prussia, a good many years ago, I was particularly impressed with hearing Old Fritz and Leibnitz spoken of as the two greatest men of the kingdom. Old Fritz made Prussia a kingdom by fighting it into position and power, and Leibnitz founded the Berlin Academy; and the Prussians themselves were intelligent enough to know that in Old Fritz and the Berlin Academy are the strength and glory, not only of old Prussia, but also of new Prussia. The whole world knows that the founding of the Berlin University in the time of national peril made new Prussia the strength and glory of science and of truth in Europe.

I see a venerable gentleman, said the Chairman, who, take it all in all, has done more for horticulture and agriculture than any other man in this country, and who now represents at this table the Historic, Genealogical Society, — the Hon. MARSHALL P. WILDER. I am unwilling to deprive him of the opportunity of speaking, and us the opportunity and pleasure of hearing a word from him at this time. Mr. Wilder spoke as follows: —

Mr. President: — If an avalanche from my native hills had slid down upon me, I should not have been more surprised than I am now that you should have called upon me so early in the ceremonies of this hour. I thank you, sir, from the bottom of my heart, for the very kind manner in which you have introduced me, and I beg to say that it will be a red-letter day in my register that I have been able to be present, after months of confinement, to meet again so many familiar faces with whom I have been long associated. I thank you, sir, most sincerely, for recognizing here the New England Historic, Genealogical Society. We are, sir, but an infant institution compared with that glorious society over which you so ably preside. But our object is the same; it is to gather up, record, and perpetuate everything that appertains to the wonderful progress of art, science, and civilization in our day. And this is not, Mr. Chairman and gentlemen, this is not the result of chance. No, no! it is the result of the teachings of such associations as your own, the exercise of the mind, the power of mind over matter, the domination of man over nature, elevating her to the highest purposes of creation. I thank you for referring to me as you have in connection with the great industrial pursuits of our land. You do me no more than justice when you say I have been deeply interested in these pursuits. I cannot remember the time, from the day my mother first took me into the garden to help dress and keep it, that I have not loved the cultivation of the soil. I love everything that appertains to rural life and pleasure. And, sir, I have lived, and you have lived, to see wonderful progress in our day in the horticulture and agriculture of our country. When your society was formed there was not an agricultural or horticultural society on this continent; now they are scattered from the Atlantic to the Pacific; from the Dominion in the North to the Gulf on the South; and on the books of the department at Washington are now enrolled more than fifteen hundred agricultural, horticultural, and kindred institutions. I cannot remember quite back to the landing of the Mayflower at Plymouth, but we are told that at one time the old colonists were reduced to the small pittance of a bushel of corn; look at that product in America now, — fifteen hundred millions of bushels a year, and the crop of wheat nearly five hundred millions of bushels; and our Western granaries are storehouses upon which the world may draw for their supplies to meet all deficiencies. I shall not detain you any longer, except to thank you for the respect and attention you have given an old man. But, like my friend on the right (Mr. Emerson), with whom I have been conversing, — he says he should like to live forty years more, — I should like to live to be present at your next centennial. Wishing you and your association prosperity, I will say, "Go on, prospering and to prosper"; and may your latter days be your best days, but far in the centuries of the future I hope.

Mr. ALEXANDER AGASSIZ was called upon as a representative of two or three academies, with the understanding, however, that he should not be obliged to make more than one speech. He said: —

Mr. President and Gentlemen: — This is the first intimation I have had that I was a representative of any society here; but, as I generally appear under somewhat dubious conditions, I am very much obliged to the President for not calling upon me, as I am usually called upon, as "the distinguished son of a distinguished father." I have become so accustomed to this that I have begun to doubt whether I have any identity of my own; and it reminds me of a similar occasion when, not the great Beethoven, but another Beethoven, was called upon to speak. He was himself the son of a distinguished musician, and the father of the great Beethoven, and he said he did not know whether he was to answer for his father or for his son, whom he expected to become a very distinguished individual. And as I am in about the same position — my oldest son expects to enter Cambridge the coming year — I will simply express the hope that he will be the distinguished member of the family. But, Mr. President, there is one society for whom I believe I am a representative, which you did not mention, and that is the Academy of Bologna; and I suppose that the reason for which I was chosen as the representative of that society is that Bologna has always been famous for the support which it has given to the education of women. Now, if I am not mistaken, about a year ago, with some other gentlemen connected with the college, we made a faint attempt to enlarge the boundaries, not of Harvard College, but of the Harvard Medical School, in which we most signally failed; and I suppose it is to alleviate my feeling of disappointment that Bologna, which has had among its professors of medicine some most distinguished women, has chosen me to represent her on this occasion, and to send her congratulations to our Academy.

Dr. HENRY O. MARCY, of Cambridge, responded as a delegate from the Academy of Sciences of Bologna in these words: —

It gave him great pleasure to present the congratulations of the Academy at Bologna to this assembly, gathered to celebrate the Centennial Anniversary of the American Academy of Arts and Sciences.

Italy looks with profound respect upon the institutions of learning in their vigorous growth and development in America.

Other speakers have discussed the priority of the establishment of the various scientific bodies here represented. The Academy of Sciences at Bologna was established in the sixteenth century; but it will be remembered that it is itself the child of the University so celebrated during the many centuries at Bologna. When thus considered, it certainly looks upon this Academy of Arts and Sciences, although dignified with age to us, as a pretending stripling, for it has had occasion to hold more than fourteen such centennial celebrations.

This old University has clustering about it memories of deeper interest than that of any other institution of learning in the civilized world. From it radiated an influence which stamped its impress upon the culture of all Europe for many centuries. It was the first to confer upon its students academic degrees, and continued to be the great centre of learning throughout the Middle Ages.

It counted its students, during the fourteenth, fifteenth, and sixteenth centuries, literally by the thousand. Here was first inaugurated, during the fourteenth century, dissections of the human body in the study of anatomy.

The great Italian masters of anatomy, who took up its study where Galen had left it, in the first century, full of mysticism and superstition, and developed it into an exact science, were here enrolled as professors. Malphigi, Murgani, and many scarcely less distinguished, were of Bologna.

As Professor Agassiz has told you, for centuries some of the most learned women in the world have been teachers in this celebrated institution.

From its history we may gather lessons of great interest and value. We learn how wisely and carefully science was encouraged at a period still shrouded in the mists of the dark ages; how church and state threw around it their fostering care; and under such influences it grew to be a great power, diffusing light and knowledge through the centuries, culturing alike the priest, the man of letters, and the armed knight, until even to-day, when science, diffused through all lands, has raised up many rivals, and although learning has been much depressed by the political changes of the last quarter of a century in Italy, this old University is yet in a flourishing condition, and numbers at the present time more than six hundred students.

In closing, I should fail to do myself justice did I not pay tribute to the Secretary of the Academy of Sciences at Bologna, Professor G. B. Ercolani, a man, although yet young, who has contributed to science, in histology, comparative anatomy, and embryology, work which will compare favorably with that of any of the present day, and will couple his name in the future with the great masters of early Italian fame.

Letters of thanks, sympathy, and congratulation were received from many of the foreign Academies and Societies which had been invited to participate in the celebration, as follows:

QUEBEC. Literary and Historical Society.
HALIFAX. Nova-Scotian Institute of Natural Science.
MEXICO. Museo Nacional.
" Sociedad Mexicana de Geographia y Estadistica.
CAMBRIDGE. Philosophical Society.
" University.
LONDON. British Association.
" Institution of Civil Engineers.
" Linnean Society.

LONDON. Royal Horticultural Society.
" Royal Institution of Great Britain.
" Royal Society.
" Statistical Society.
BARNSLEY. Midland Institute of Mining, Civil, and Mechanical Engineers.
MANCHESTER. Literary and Philosophical Society.
NEWCASTLE-UPON-TYNE. Institute of Mining and Mechanical Engineers.
PENZANCE. Royal Geological Society of Cornwall.
EDINBURGH. Royal Society.
" Royal Scottish Society of Arts.
DUBLIN. Royal Geological Society of Ireland.
" Institution of Civil Engineers.
AMSTERDAM. Koninklijke Akademie van Wetenschappen.
THE HAGUE. Koninklijk Instituut voor de Taal-, Land- en Volkenkunde van Nederlandsch Indië.
HAARLEM. Hollandsche Maatschappij van Wetenschappen.
" Teyler's Stichtung.
LEIDEN. Rijks Observatorium.
MIDDELBURG. Zeeuwsche Genootschap van Wetenschappen.
UTRECHT. Koninklijk Nederlandsch Meteorologisch Instituut.
BRUSSELS. Académie Royale des Sciences, &c.
" Observatoire Royal.
" Société Entomologique de Belgique.
LIEGE. Société Géologique de Belgique.
COPENHAGEN. Kongelige Nordiske Oldschrift-Selskab.
" Kongelige Danske Videnskabernes Selskab.
CHRISTIANIA. Kongslige Frederiks Universitet.
LUND. Kongliga Universitet.
STOCKHOLM. Kongliga Svenska Vetenskaps-Akademien.
" Nautisk Mâteorologiska Byrån.
HELSINGFORS. Finska Vetenskaps Societeten.
ST. PÉTÉRSBOURG. Académie Impériale des Sciences.
" Jardin Impériale de Botanique.
MOSCOW. Société Impériale des Naturalistes.
BERN. Schweizerische Gesellschaft für die gesammten Naturwissenschaften.
BASEL. Naturforschende Gesellschaft.
BORDEAUX. Société de Géographie Commerciale.
CAEN. Académie Nationale des Sciences, &c.
CHERBOURG. Société Nationale des Sciences Naturelles.

MONTPELLIER. Académie des Sciences et Lettres.
PARIS. Observatoire Météorologique Central de Montsouris.
" Société de Géographie.
" Société Géologique de France.
BERLIN. Königlich. Preussiches Landes-Oekonomie-Collegium.
" Königlich. Preussische Akademie der Wissenschaften.
BREMEN. Naturwissenschaftlicher Verein.
BRÜNN. Naturforschende Verein.
BÜTZOW. Verein der Freunde der Naturgeschichte in Mecklenburg.
CHEMNITZ. Naturwissenschaftliche Gesellschaft.
DANZIG. Naturforschende Gesellschaft.
ELBERFELD. Naturwissenschaftlicher Verein.
EMDEN. Naturforschende Gesellschaft.
ERLANGEN. Physikalisch-Medicinische Societät.
FRANKFURT AM MAIN. Naturforschende Gesellschaft.
" " " Physikalischer Verein.
" " " Neue Zöologische Gesellschaft.
" " " Aerztlicher Verein.
FREIBERG. Königlich-Sächsische Bergakademie.
FREIBURG. Naturforschende Gesellschaft.
GIESSEN. Oberhessische Gesellschaft für Natur- und Heilkunde.
GÖRLITZ. Naturforschende Gesellschaft.
" Oberlausitzische Gesellschaft der Wissenschaften.
GÖTTINGEN. Königliche Gesellschaft der Wissenschaften.
HALLE. Kaiserliche Leopoldinisch-Carolinische Deutsche Akademie der Naturforscher.
HEIDELBERG. Naturhistorisch-Medecinischer Verein.
KÖNIGSBERG. Physikalisch-ökonomische Gesellschaft.
LEIPZIG. Astronomische Gesellschaft.
MANNHEIM. Verein für Naturkunde.
MARBURG. Gesellschaft zur Beförderung der gesammten Naturwissenschaften.
MULHOUSE. Société Industrielle.
MUNICH. Königl. Bayerische Akademie der Wissenschaften.
POSEN. Naturwissenschaftlicher Verein.
PRAGUE. K. K. Sternwarte.
STETTIN. Entomologischer Verein.
STUTTGART. Verein für Vaterländ. Naturkunde in Würtemberg.
VIENNA. Kaiserliche Akademie der Wissenschaften.
" K. K. Geologische Reichsanstalt.
" K. K. Zoologisch-Botanische Gesellschaft.
" Verein zur Verbreitung naturwissenschaftlicher Kenntnisse.

Bologna. Accademia delle Scienze.
Catania. Accademia Gioenia di Scienze Naturali.
Lucca. Reale Accademia Lucchese di Scienze, &c.
Pisa. Reale Università.
Rome. Reale Accademia dei Lincei.
Turin. Reale Accademia delle Scienze.
Venice. R. Istituto Veneto di Scienze, &c.
Madrid. Observatorio Astronomico.
San Fernando. Observatorio de Marina.
Port Louis. (Mauritius). Royal Society of Arts and Sciences.
Calcutta. Geological Society of India.
Batavia. Bataaviasch Genootschap van Kunsten en Wetenschappen.
" Koninlijke Naturkundige Vereeniging in Nederlandsch-Indië.
Sydney. Royal Society of New South Wales.
Melbourne. Royal Society of Victoria.

In reply to invitations sent to the Foreign Honorary Members of the Academy, letters of acknowledgment and of felicitation were received from the following: —

John C. Adams, Cambridge.
J. G. Agardh, Lund.
G. B. Airy, Greenwich.
Joachim Barrande, Prague.
George Bentham, London.
R. W. Bunsen, Heidelberg.
Alphonse de Candolle, Geneva.
Arthur Cayley, Cambridge.
Rudolph Clausius, Bonn.
Georg Curtius, Leipsic.
Charles Darwin, Beckenham.
Wilhelm Döllen, Pulkowa.
H. M. Edwards, Paris.
Oswald Heer, Zurich.
Hermann Helmholtz, Berlin.
Joseph D. Hooker, London.
J. P. Joule, Manchester.
Gustav Kirchhoff, Berlin.
R. Leuckart, Leipsic.
Henry S. Maine, London.
James Martineau, London.
Charles Merivale, Ely.
W. H. Miller, Cambridge.
Richard Owen, London.
James Paget, London.
Leopold Von Ranke, Berlin.
James F. Stephen, London.
Balfour Stewart, Manchester.
G. G. Stokes, Cambridge.
Otto Struve, Pulkowa.
J. J. Sylvester, Baltimore.
Alfred Tennyson, Freshwater, I. W.
Friedrich Wöhler, Göttingen.

THE CENTENNIAL PUBLICATION FUND.

This fund owes its origin to one of the Fellows, Dr. Benjamin E. Cotting, who, at a meeting of the academic council, presented one thousand dollars as the first subscription. The Centennial Committee, having authority from the Academy to solicit subscriptions, appointed a Sub-Committee on a Centennial Publication Fund, consisting of J. Ingersoll Bowditch, William B. Rogers, John A. Lowell, Nathaniel Thayer, H. H. Hunnewell, E. B. Bigelow, and B. E. Cotting. They also issued the following appeal, and sought subscriptions by personal application.

The accompanying sketch sets forth the past history and present needs and claims of the American Academy of Arts and Sciences.

The income of the American Academy is derived from two sources: Assessments on its members, $1,900; and interest of General Fund, $1,200; making a total of about $3,100. The Academy also administers the Rumford Fund, which, however, is strictly limited by the terms of the trust. After paying $2,250 for rent, books, and salary of Assistant Librarian, there remain but $850 a year for publishing the Proceedings and Memoirs, a sum barely sufficient to pay for a portion of the ordinary printing, leaving no provision for engravings, or for publishing the more costly Memoirs. This lack will be appreciated when it is brought to mind that the usefulness and distinction of such a Society depend almost entirely on its power of publishing important papers promptly and with proper illustrations.

In honor of its hundredth Anniversary, the Fellows of the Academy hope to raise the sum of $50,000 as a permanent Publication Fund, the income to be applied to publishing the transactions of the Society.

Contributions are respectfully solicited, and may be sent to

THEODORE LYMAN, *Treasurer*,
191 Commonwealth Avenue, Boston.

26 December, 1879.

The American Academy of Arts and Sciences, which was chartered by the Commonwealth of Massachusetts, on the fourth day of May, 1780, proposes to celebrate its Centennial Anniversary, in the ensuing month of May, 1880.

This is the oldest institution of the kind in America, excepting the American Philosophical Society at Philadelphia. That was initiated by Franklin and others, before the beginning of the war for independence; this was inaugurated before the close of that war. The preamble to the charter sets forth, that, —

"As the arts and sciences are the foundation and support of agriculture, manufactures, and commerce; as they are necessary to the wealth, peace, independence, and happiness of a people; essentially promote the honor and dignity of the government which patronizes them; and as they are most effectually cultivated and diffused through a State by the forming and incorporating of men of genius and learning into public Societies:"

For these beneficial purposes the Academy was formed.

The list of incorporated members, recited in alphabetical order, includes the honored names of Adams (Samuel and John), Bowdoin, Chauncy, Cushing, Dalton, Dana, Gardner, Hancock, Holyoke, Jackson, Lincoln, Lowell, Oliver, Paine, Phillips, Pickering, Sewall, Sullivan, Warren, Wigglesworth, Willard and Winthrop. Governor Bowdoin was the first President, and his successors were: John Adams, Edward Augustus Holyoke, John Quincy Adams, Nathaniel Bowditch, James Jackson, John Pickering, Jacob Bigelow, Asa Gray, and Charles Francis Adams.

The Academy had an honorable origin, and has sustained, and still holds, an honored position among the learned Societies of the world. It is favorably known among its peers, if less known in the city and community in which its quiet operations have been carried on. It has promoted investigation; it has published at its own expense, out of scanty means, nearly thirty volumes of Memoirs and Proceedings; and most of its publications are original contributions to Science in the broadest sense, and to the liberal and useful Arts. Increasing its activity with the increase of scientific men and earnest students in this vicinity, its published results have become more and more numerous as well as more valuable; and for several years past it has brought out a yearly volume of researches which it is thought would be creditable to any of the Royal Societies and Imperial Academies of Europe. The influence of the Academy upon the progress of science would have more prominently appeared if its pecuniary means were at all proportioned to the scientific activity it has incited. For lack of means, many important researches here originated are published elsewhere, or remain unpublished, or are shorn of needful illustration.

The Academy is also the administrator of a responsible trust, founded by Count Rumford, for the advancement of the knowledge of light and heat and of their practical applications. Moreover, the Academy has slowly accumulated a library of special richness in the departments of physics, chemistry, technology and mathematics, and in the transactions of the learned societies with which it corresponds; and it has no place of its own in which to preserve and use it.

Upon attaining what may be called its majority, the Academy will make an effort to obtain a modest independent establishment. It has formed its character; it has earned a good name. It wants a local habitation, a house of its own, where its meetings can be held and its archives and library preserved and conveniently used. Even more, it wants a fund for the publication of its Memoirs and Proceedings. The Academy is supported mainly by assessments upon its Resident Fellows, which sometimes press heavily upon those to whom the institution is most helpful and whose labors may be expected to add most to its renown. To the publication of the results of the self-denying labors of the men whose minds it stimulates, and whose success it crowns and secures by bringing them before the scientific world, the Academy is indebted for its reputation; and it is only by such publication that its character can be maintained and extended.

The learned Societies of other countries are endowed or supported by the State, upon reasons which are suggested by the preamble to the charter of our Academy, above recited. Such duties in this country devolve upon the community as individuals. The Fellows of the Academy will do all they can. But if they are right in their opinion that the institution they represent has contributed to the intellectual character and the material prosperity of the city of Boston and the Commonwealth of Massachusetts, during the century now closing, they may hopefully solicit the aid which is essential to greater usefulness in the future.

ROBERT C. WINTHROP,
JOHN AMORY LOWELL, ASA GRAY,
NATHANIEL THAYER, WILLIAM B. ROGERS,
B. E. COTTING, H. H. HUNNEWELL,
J. INGERSOLL BOWDITCH, JOSIAH P. COOKE, JR.,
ALEXANDER AGASSIZ, THEODORE LYMAN,
ROBERT AMORY, EDWARD ATKINSON,
Centennial Committee.

The sum of $35,585 was given by the following persons:—

Charles Francis Adams	$5,000	Alexander Agassiz	$5,000
J. Ingersoll Bowditch (In Memoriam N. B.)	5,000	H. H. Hunnewell	5,000
Theodore Lyman	1,500	B. E. Cotting	1,000
Mrs. E. F. Bigelow (In Memoriam E. B. B.)	1,000	H. P. Kidder	1,000
John L. Gardner	1,000	George C. Richardson	1,000
John A. Lowell	1,000	J. P. Cooke	500
Alexander G. Bell	500	H. W. Williams	500
"S"	500	Robert C. Winthrop	500
Charles E. Ware	500	S. P. Ruggles	500
Robert C. Winthrop, Jr.	500	Dr. W. S. Bigelow	250
George Higginson	300	Dr. R. W. Hooper	250
Asa Gray	250	Mrs. G. H. Shaw	100
Charles S. Sargent	100	E. S. Dixwell	100
J. B. Upham	100	Dr. A. Hosmer	100
John Lowell	100	Dr. G. E. Ellis	100
Augustus Flagg	100	O. W. Peabody	100
Moses G. Farmer	100	Calvin Ellis	100
Francis Bartlett	100	"B"	100
H. L. Daggett	100	R. C. Greenleaf	100
Lyman Hollingsworth	100	C. M. Warren	100
W. D. Pickman	100	George B. Emerson	100
C. P. Curtis	100	Mrs. J. Richardson	100
G. R. Minot (In Memoriam G. R. M.)	100	E. D. Leavitt, Jr.	100
H. F. Mills	100	Samuel Eliot	100

JOHN DEAN	$100
T. S. HUNT	100
EZRA ABBOT	50
MRS. J. E. LODGE	50
S. H. SCUDDER	20
CHARLES R. CROSS	10
HENRY MITCHELL	10
MRS. THOMAS COLE, SALEM (IN MEMORIAM THOMAS COLE)	$100
H. C. LODGE	50
DR. ROBERT AMORY	25
A MEMBER	10
J. J. PUTNAM	10

MEMBERS OF THE ACADEMY.

In the original constitution of the Academy all the members were designated as Fellows. But in the first two volumes of printed Memoirs they are divided into three classes: — 1, Home Members; 2, American Members; and 3, Foreign Members. In the third and fourth volumes of the Memoirs they are separated into two classes: — 1, Resident Members; and 2, Honorary Members. In the first and second volumes of the Second Series of Memoirs, they are printed in three classes: — 1, Members Resident in Massachusetts; 2, American Honorary Members; and 3, Foreign Honorary Members. In 1854 the constitution was amended, so as to provide for the election of 1, Fellows (who reside in Massachusetts); 2, Associate Fellows (who reside in other States of the Union); and 3, Foreign Honorary Members. The following catalogue of Fellows includes not only those members who resided in Massachusetts, but all other American members who were dead at the time when the constitution was amended. The catalogue of Foreign Honorary Members contains the names of all foreign members, whether they were elected before or after the constitution was amended.

FELLOWS.

I. Fellows Incorporated May 3, 1780.

Samuel Adams, Boston. Died 2 October, 1803, aged 81.
John Adams, Braintree. Died 4 July, 1826, aged 90.
John Bacon, Stockbridge. Died 25 October, 1820, aged 83.
James Bowdoin, Boston. Died 6 November, 1790, aged 63.
Charles Chauncy, Boston. Died 10 February, 1787, aged 82.
John Clarke, Boston. Died 2 April, 1798, aged 42.
David Cobb, Taunton. Died 17 April, 1830, aged 81.
Samuel Cooper, Boston. Died 29 December, 1783, aged 58.
Thomas Cushing, Boston. Died 28 February, 1788, aged 62.
Nathan Cushing, Scituate. Died 3 November, 1812, aged 70.
William Cushing, Scituate. Died 13 September, 1810, aged 77.
Tristram Dalton, Newburyport. Died 30 May, 1817, aged 79.

Francis Dana, Cambridge. Died 25 April, 1811, aged 67.

Samuel Deane, Falmouth. Died 12 November, 1814, aged 81.

Perez Fobes, Raynham. Died 23 February, 1812, aged 69.

Caleb Gannett, Cambridge. Died 25 April, 1818, aged 72.

Henry Gardner, Boston. Died 7 October, 1782, aged 50.

Benjamin Guild, Cambridge. Died October, 1792, aged 43.

John Hancock, Boston. Died 8 October, 1793, aged 56.

Joseph Hawley, Northampton. Died 10 March, 1788, aged 64.

Edward Augustus Holyoke, Salem. Died 31 March, 1829, aged 100.

Ebenezer Hunt, Northampton. Died 26 December, 1820, aged 76.

Jonathan Jackson, Newburyport. Died 5 March, 1810, aged 66.

Charles Jarvis, Boston. Died 15 November, 1807, aged 59.

Samuel Langdon, Cambridge. Died 29 November, 1797, aged 74.

Levi Lincoln, Worcester. Died 14 April, 1820, aged 70.

Daniel Little, Wells. Died 5 December, 1801, aged 78.

Elijah Lothrop, Boston. Died in 1797?

John Lowell, Boston. Died 6 May, 1802, aged 58.

Samuel Mather, Boston. Died 27 June, 1785, aged 78.

Samuel Moody, Newbury. Died 14 December, 1795, aged 70.

Andrew Oliver, Salem. Died December, 1799, aged 68.

Joseph Orne, Salem. Died 28 January, 1786, aged 38.

Robert Treat Paine, Taunton. Died 11 May, 1814, aged 83.

Theodore Parsons, Newbury. Lost at sea, 1779, aged 28.

George Partridge, Duxbury. Died 7 July, 1828, aged 88.

Phillips Payson, Chelsea. Died 11 January, 1801, aged 64.

Samuel Phillips, Andover. Died 10 February, 1802, aged 50.

John Pickering, Salem. Died 20 August, 1811, aged 71.

Oliver Prescott, Groton. Died 17 November, 1804, aged 73.

Zedekiah Sanger, Duxbury. Died 17 November, 1820, aged 72.

Nathaniel Peaslee Sargeant, Haverhill. Died October, 1791, aged 60.

Micajah Sawyer, Newburyport. Died 29 September, 1815, aged 78.

Theodore Sedgwick, Sheffield. Died 24 June, 1813, aged 66.

William Sever, Kingston. Died 15 June, 1809, aged 79.

Stephen Sewall, Cambridge. Died 23 July, 1804, aged 70.

David Sewall, York. Died 22 October, 1825, aged 90.

John Sprague, Lancaster. Died September, 1800, aged 60.

Ebenezer Storer, Boston. Died 6 January, 1807, aged 76.

Caleb Strong, Northampton. Died 7 November, 1819, aged 74.

James Sullivan, Groton. Died 10 December, 1808, aged 64.

John Barnard Swett, Marblehead. Died August, 1796, aged 44.

Nathaniel Tracy, Newburyport. Died in 1796.

Cotton Tufts, Weymouth. Died 8 December, 1815, aged 81.

James Warren, Plymouth. Died 27 November, 1808, aged 82.

Samuel West, Dartmouth. Died 24 September, 1807, aged 77.

Edward Wigglesworth, Cambridge. Died 17 June, 1794, aged 62.

Joseph Willard, Beverly. Died 25 September, 1804, aged 65.

Samuel Williams, Bradford. Died 2 January, 1817, aged 73.

Abraham Williams, Sandwich. Died 3 August, 1784, aged 57.

Nehemiah Williams, Brimfield. Died 26 November, 1796, aged 47.

James Winthrop, Cambridge. Died 26 September, 1821, aged 72.

II. Fellows Elected.

31 January, 1781.

Richard Cranch, Braintree. Died 16 October, 1811, aged 84.

Manasseh Cutler, Ipswich. Died 28 July, 1823, aged 81.

Timothy Danielson, Brimfield. Died 19 September, 1791, aged 57.

Timothy Edwards, Stockbridge. Died 27 October, 1813, aged 75.

Benjamin Franklin, Philadelphia. Died 17 April, 1790, aged 84.

Elbridge Gerry, Marblehead. Died 23 November, 1814, aged 70.

Ebenezer Hazard, Philadelphia. Died 13 June, 1817, aged 72.

Benjamin Lincoln, Hingham. Died 9 May, 1810, aged 77.

Samuel Osgood, Andover. Died 12 August, 1813, aged 65.

Theophilus Parsons, Newburyport. Died 30 October, 1813, aged 63.

Eliphalet Pearson, Andover. Died 12 September, 1826, aged 74.

Ezra Stiles, New Haven. Died 12 May, 1795, aged 67.

George Washington, Mount Vernon, Virginia. Died 14 December, 1799, aged 67.

Benjamin West, Providence. Died 13 August, 1813, aged 83.

22 August, 1781.

Joseph Brown, Providence. Died 3 December, 1785, aged 52.

Benjamin Gale, Killingworth, Connecticut. Died 21 May, 1790, aged 75.

Simeon Howard, Boston. Died 13 August, 1804, aged 71.

John Warren, Boston. Died 4 April, 1815, aged 61.

30 January, 1782.

Loammi Baldwin, Woburn. Died 20 October, 1807, aged 62.

Owen Biddle, Philadelphia. Died 10 March, 1799, aged 61.

Arthur Lee, Urbanna, Virginia. Died 12 December, 1792, aged 51.

William Livingston, Elizabethtown, New Jersey. Died 25 July, 1790, aged 66.

David Rittenhouse, Philadelphia. Died 26 June, 1796, aged 64.

Jonathan Trumbull, Lebanon, Connecticut. Died 17 August, 1785, aged 74.

Meshech Weare, Hampton, New Hampshire. Died 14 January, 1786, aged 72.

1 April, 1784.

Thomas Dawes, Boston. Died 2 January, 1809, aged 77.

Joshua Fisher, Beverly. Died 21 March, 1833, aged 83.

25 May, 1784.

William Erving, Boston. Died 27 May, 1791, aged 56.

Samuel Hale, Portsmouth. Died 16 July, 1807, aged 88.

John Sparhawk, Portsmouth.

25 August, 1784.

Aaron Dexter, Boston. Died 28 February, 1829, aged 78.

26 January, 1785.

Jeremy Belknap, Dover, New Hampshire. Died 20 June, 1798, aged 53.

John Prince, Salem. Died 7 June, 1836, aged 84.

23 August, 1786.

James Bowdoin, Dorchester, Died 11 October, 1811, aged 59.

John Jones Spooner, Roxbury. Died 6 April, 1799, aged 41.

Samuel Vaughan, Philadelphia. Died 4 December, 1802, aged 83.

Nathaniel Wells, Wells. Died 6 December, 1816, aged 76.

29 May, 1787.

Thomas Jefferson, Monticello, Virginia. Died 4 July, 1826, aged 83.

30 April, 1788.

Thomas Russell, Boston. Died 8 April, 1796, aged 55.

Noah Atwater, Westfield. Died 25 January, 1802, aged 50.

20 August, 1788.

George Cabot, Beverly. Died 18 April, 1823, aged 71.

Nicholas Pike, Newburyport. Died 9 December, 1819, aged 76.

Joseph Pope, Boston. Died August, 1826, aged 79.

Benjamin Rush, Philadelphia. Died 19 April, 1813, aged 67.

Winthrop Sargent, Natchez, Mississippi. Died 3 June, 1820, aged 67.

28 January, 1789.

George Richards Minot, Boston. Died 2 January, 1802, aged 43.

29 May, 1789.

Nathaniel Walker Appleton, Boston. Died 15 April, 1795, aged 39.

William Baylies, Dighton. Died 17 June, 1826, aged 82.

2 December, 1789.

Samuel Danforth, Boston. Died 16 November, 1827, aged 87.

Samuel Webber, Cambridge. Died 17 July, 1810, aged 50.

27 January, 1790.

Samuel Kirkland, Oneida, New York. Died 28 February, 1808, aged 66.

Solomon Drown, Providence. Died 5 February, 1834, aged 80.

25 August, 1790.

Samuel Shaw, Bridgewater. Died 30 May, 1794, aged 39.

John Lathrop, Boston. Died 4 January, 1816, aged 75.

John Jay, New York. Died 17 May, 1829, aged 83.

24 August, 1791.

Charles Bulfinch, Boston. Died 15 April, 1844, aged 80.

John Trumbull, Lebanon, Connecticut. Died 10 November, 1843, aged 87.

Nathan Read, Salem. Died 20 January, 1849, aged 89.

John Trumbull, Hartford, Connecticut. Died 10 May, 1831, aged 81.

Increase Sumner, Roxbury. Died 7 June, 1799, aged 52.

Samuel Dexter, Weston. Died 10 June, 1810, aged 84.

John Pickering, Portsmouth, New Hampshire. Died 11 April, 1805, aged 67.

Samuel Tenney, Exeter, New Hampshire. Died 6 February, 1816, aged 67.

William Paine, Salem. Died 19 April, 1833, aged 82.

Alexander Hamilton, New York. Died 12 July, 1804, aged 47.

29 May, 1792.

Joseph Lathrop, West Springfield. Died 31 December, 1820, aged 89.

John Davis, Plymouth. Died 14 January, 1847, aged 85.

John Mellen, Barnstable. Died 19 September, 1828, aged 76.

30 January, 1793.

William Dandridge Peck, Kittery. Died 3 October, 1822, aged 59.

Oliver Everett, Dorchester. Died 19 December, 1802, aged 49.

Benjamin Smith Barton, Philadelphia. Died 19 December, 1815, aged 49.

James Freeman, Boston. Died 14 November, 1835, aged 76.

Fisher Ames, Dedham. Died 4 July, 1808, aged 50.

27 May, 1794.

Charles Vaughan, Boston. Died 15 May, 1839, aged 79.

James Madison, Williamsburg, Virginia. Died 6 March, 1812, aged 62.

Benjamin Dearborn, Boston. Died 22 February, 1838, aged 82.

Nathaniel Appleton, Boston. Died 26 June, 1798, aged 66.

26 May, 1795.

Thomas Dawes, Boston. Died 21 July, 1825, aged 68.
Thomas Welsh, Boston. Died 9 February, 1831, aged 79.
Benjamin Waterhouse, Cambridge. Died 2 October, 1846, aged 92.

24 August, 1796.

Joseph McKeen, Beverly. Died 15 July, 1807, aged 49.
Peter Thacher, Boston. Died 16 December, 1802, aged 50.
Jedidiah Morse, Charlestown. Died 9 June, 1826, aged 64.
Isaac Rand, Boston. Died 11 December, 1822, aged 79.

9 November, 1796.

Christopher Gore, Waltham. Died 1 March, 1827, aged 68.
Thomas Brattle, Cambridge. Died 7 February, 1801, aged 59.
William Spooner, Boston. Died 15 February, 1836, aged 75.
David Tappan, Cambridge. Died 27 August, 1803, aged 51.

25 January, 1797.

John Halliburton, Halifax, Nova Scotia.

30 May, 1797.

Samuel Latham Mitchill, New York. Died 7 September, 1831, aged 67.
Timothy Dwight, New Haven. Died 11 January, 1817, aged 64.

23 August, 1797.

John Quincy Adams, Quincy. Died 23 February, 1848, aged 80.

22 August, 1798.

Thomas Barnard, Salem. Died 1 October, 1814, aged 66.
Theophilus Bradbury, Newburyport. Died 6 September, 1803, aged 63.

28 May, 1799.

John Thornton Kirkland, Boston. Died 26 April, 1840, aged 69.
Nathaniel Bowditch, Salem. Died 16 March, 1838, aged 64.
Noah Webster, New Haven. Died 28 May, 1843, aged 84.

21 August, 1799.

Edward Hutchinson Robbins, Milton. Died 29 December, 1829, aged 72.

29 January, 1800.

Samuel Dexter, Charlestown. Died 4 May, 1816, aged 55.

20 August, 1800.

Benjamin De Witt, Albany, New York. Died 11 September, 1819, aged 45.

28 January, 1801.

Samuel Sewall, Marblehead. Died 8 January, 1814, aged 56.
William Paterson, Brunswick, New Jersey. Died 9 September, 1806, aged 61.

24 May, 1803.

Josiah Quincy, Boston. Died 1 July, 1864, aged 92.
Timothy Bigelow, Groton. Died 18 May, 1821, aged 54.
Oliver Ellsworth, Windsor, Connecticut. Died 26 November, 1807, aged 62.
Abiel Holmes, Cambridge. Died 4 June, 1837, aged 73.
William Emerson, Boston. Died 12 May, 1811, aged 42.
James Thacher, Plymouth. Died 24 May, 1844, aged 90.

24 August, 1803.

Caspar Wistar, Philadelphia. Died 22 January, 1818, aged 56.
Allan Pollock, Boston. Died in 1859.

24 January, 1804.

Henry Ware, Hingham. Died 12 July, 1845, aged 81.

John Marshall, Richmond, Virginia. Died 6 July, 1835, aged 79.

John Lowell, Boston. Died 12 March, 1840, aged 70.

Joseph Lyman, Hatfield. Died 27 March, 1828, aged 78.

29 May, 1804.

David Humphreys, New Haven. Died 21 February, 1818, aged 65.

Jonathan Trumbull, Lebanon, Connecticut. Died 7 August, 1809, aged 69.

14 August, 1804.

Harrison Gray Otis, Boston. Died 28 October, 1848, aged 83.

Samuel Williams, London. Died 6 June, 1841, aged 81.

Joshua Thomas, Plymouth. Died 10 January, 1821, aged 69.

13 February, 1805.

John Eliot, Boston. Died 14 February, 1813, aged 58.

Levi Hedge, Cambridge. Died 3 January, 1844, aged 77.

Aaron Bancroft, Worcester. Died 19 August, 1839, aged 83.

Henry Knox, Thomaston. Died 25 October, 1806, aged 56.

Rufus King, New York. Died 29 April, 1827, aged 72.

Benjamin Vaughan, Hallowell. Died 8 December, 1835, aged 84.

13 November, 1805.

John Treadwell, Farmington, Connecticut. Died 19 August, 1823, aged 77.

29 January, 1806.

Daniel Kilham, Wenham. Died October, 1841, aged 88.

27 May, 1806.

Thaddeus Mason Harris, Dorchester. Died 3 April, 1842, aged 73.

12 November, 1806.

Samuel Eliot, Boston. Died 18 January, 1820, aged 81.

Dudley Atkins Tyng, Boston. Died 1 August, 1829, aged 68.

12 August, 1807.

Thomas Thacher, Dedham. Died 19 October, 1812, aged 56.

11 November, 1807.

Francis Adrian Van der Kemp, Oldenbarneveld, New York. Died 7 September, 1829, aged 77.

27 January, 1808.

James Jackson, Boston. Died 27 August, 1867, aged 89.

John Collins Warren, Boston. Died 4 May, 1856, aged 77.

John Clarke Howard, Boston. Died 11 August, 1810, aged 28.

Sidney Willard, Cambridge. Died 6 December, 1856, aged 76.

John Farrar, Cambridge. Died 8 May, 1853, aged 73.

10 August, 1808.

Stephen Elliott, Beaufort, South Carolina. Died 28 March, 1830, aged 58.

John Snelling Popkin, Newbury. Died 2 March, 1852, aged 80.

John Allyn, Duxbury. Died 19 July, 1833, aged 66.

9 November, 1808.

Silvain Godon, Philadelphia. Died 27 October, 1840, aged 66.

Constantino Samuele Rafinesque-Schmaltz, Lexington, Ky. Died 18 September, 1840, aged 56.

9 August, 1809.

Charles Stearns, Lincoln. Died 26 July, 1826, aged 74.

Joseph Stevens Buckminster, Boston. Died 9 June, 1812, aged 28.

John Pierce, Brookline. Died 24 August, 1849, aged 76.

William Ellery Channing, Boston. Died 2 October, 1842, aged 62.

31 January, 1810.

John Gorham, Boston. Died 27 March, 1829, aged 46.

Redford Webster, Boston. Died 31 August, 1833, aged 72.

Joseph Story, Salem. Died 10 September, 1845, aged 65.

James Mann, Wrentham. Died 7 November, 1832, aged 73.

George Cheyne Shattuck, Boston. Died 18 March, 1854, aged 70.

29 May, 1810.

Thomas Boylston Adams, Quincy. Died 12 March, 1832, aged 59.

John Pickering, Salem. Died 5 May, 1846, aged 69.

Jesse Appleton, Brunswick. Died 12 November, 1819, aged 46.

Loammi Baldwin, Charlestown. Died 30 June, 1838, aged 58.

Richard Sullivan, Brookline. Died 12 December, 1861, aged 82.

14 November, 1810.

Oliver Fiske, Worcester. Died 25 January, 1837, aged 74.

William Smith Shaw, Boston. Died 25 April, 1826, aged 47.

Eliphalet Porter, Roxbury. Died 7 December, 1833, aged 75.

John Phillips, Boston. Died 29 May, 1823, aged 52.

28 May, 1811.

Samuel Cooper Thacher, Boston. Died 2 January, 1818, aged 32.

Isaac Parker, Boston. Died 26 May, 1830, aged 61.

James Dean, Burlington, Vermont. Died 20 January, 1849, aged 72.

Josiah Bartlett, Charlestown. Died 3 March, 1820, aged 61.

James Lloyd, Boston. Died 5 April, 1831, aged 62.

14 August, 1811.

Elisha Clap, Boston. Died 22 October, 1830, aged 54.

26 May, 1812.

George Gardner Lee, Boston. Died 13 May, 1816, aged 41.

Joseph Tilden, Boston. Died 28 July, 1853, aged 74.

Jacob Bigelow, Boston. Died 10 January, 1879, aged 91.

Leonard Woods, Andover. Died 24 August, 1854, aged 80.

Frederick Hall, Middlebury, Vermont. Died 27 July, 1843, aged 64.

19 August, 1812.

Ebenezer Adams, Hanover, New Hampshire. Died 15 August, 1841, aged 75.

Peter Oxenbridge Thacher, Boston. Died 22 February, 1843, aged 66.

Daniel Chipman, Middlebury, Vermont. Died 23 April, 1850, aged 84.

Ichabod Nichols, Portland. Died 2 January, 1859, aged 74.

Henry Channing, New York. Died 27 August, 1840, aged 81.

Elijah Paine, Williamstown, Vermont. Died 21 April, 1842, aged 85.

11 November, 1812.

Rufus Wyman, Chelmsford. Died 22 June, 1842, aged 64.

Benjamin Lynde Oliver, Salem. Died 14 May, 1835, aged 75.

John Dexter Treadwell, Salem. Died 6 June, 1833, aged 65.

Horace Holley, Boston. Died 31 July, 1827, aged 46.

Archibald Bruce, New York. Died 22 February, 1818, aged 41.

Daniel Appleton White, Newburyport. Died 30 March, 1861, aged 84.

25 May, 1813.

Samuel Swett, Boston. Died 28 October, 1866, aged 84.

Asahel Stearns, Chelmsford. Died 5 February, 1839, aged 64.

18 August, 1813.

William Sullivan, Boston. Died 3 September, 1839, aged 64.

John Garnett, New Brunswick, New Jersey. Died 11 May, 1820, aged 69.

Robert Adrain, New Brunswick, New Jersey. Died 10 August, 1843, aged 67.

Jacob Perkins, Newburyport. Died 30 July, 1849, aged 83.

George Gibbs, Boston. Died 5 August, 1833, aged 57.

10 November, 1813.

Thomas Lindall Winthrop, Boston. Died 22 February 1841, aged 81.

William Wells, Boston. Died 21 April, 1860, aged 86.

25 January, 1815.

David Hosack, New York. Died 22 December, 1835, aged 66.

Levi Frisbie, Cambridge. Died 9 July, 1822, aged 38.

Moses Stuart, Andover. Died 4 January, 1852, aged 71.

Samuel Cary, Boston. Died 22 October, 1815, aged 29.

30 May, 1815.

Andrews Norton, Cambridge. Died 18 September, 1853, aged 66.

William Prescott, Boston. Died 8 December, 1844, aged 82.

23 August, 1815.

Timothy Pickering, Salem. Died 29 January, 1829, aged 83.

Benjamin Pickman, Salem. Died 16 August, 1843, aged 80.

Horatio Gates Spafford, Albany. Died 7 August, 1832, aged 54.

13 November, 1816.

Samuel Willard, Deerfield. Died 8 October, 1859, aged 83.

DeWitt Clinton, New York. Died 11 February, 1828, aged 58.

13 August, 1817.

Charles Jackson, Boston. Died 13 December, 1855, aged 80.

26 May, 1818.

Walter Channing, Boston. Resigned 4 September, 1854.

George Hayward, Boston. Died 7 October, 1863, aged 72.

Bezaleel Howard, Springfield. Died 20 January, 1837, aged 83.

25 May, 1819.

Francis Calley Gray, Boston. Died 29 December, 1856, aged 66.

Daniel Drake, Lexington, Kentucky. Died 5 November, 1852, aged 67.

Nathan Hale, Boston. Died 8 February, 1863, aged 78.

30 May, 1820.

Daniel Webster, Boston. Died 24 October, 1852, aged 70.

Edward Everett, Cambridge. Died 15 January, 1865, aged 70.

Francis Vergnies, Newburyport. Died 1830, aged 83.

Peter Stephen Duponceau, Philadelphia. Died 1 April, 1844, aged 83.

31 January, 1821.

George Ticknor, Boston. Died 26 January, 1871, aged 79.

29 January, 1823.

John White Webster, Boston. Died 30 August, 1850, aged 57.

William Allen, Brunswick, Maine. Died 16 July, 1868, aged 84.

Samuel Farmar Jarvis, Boston. Died 26 March, 1851, aged 65.

Daniel Stansbury, Belleville, New Jersey.

John Ware, Boston. Died 29 April, 1864, aged 68.

Henry Alexander Scammel Dearborn, Boston. Died 29 July, 1851, aged 68.

Enoch Hale, Boston. Died 12 November, 1848, aged 58.

27 May, 1823.

John Brazer, Salem. Died 26 February, 1846, aged 56.

Joseph Emerson Worcester, Cambridge. Died 27 October, 1865, aged 81.

Willard Phillips, Boston. Died 9 September, 1873, aged 88.

12 November, 1823.

Caleb Cushing, Newburyport. Died 2 January, 1879, aged 78.

Edward Tyrrel Channing, Cambridge. Died 8 February, 1856, aged 65.

Samuel Howe, Northampton. Died 20 January, 1828, aged 42.

Daniel Treadwell, Boston. Died 27 February, 1872, aged 80.

Lemuel Shaw, Boston. Died 30 March, 1861, aged 80.

18 February, 1824.

James Trecothick Austin, Boston. Died 10 May, 1870, aged 86.

Alexander Hill Everett, Boston. Died 29 June, 1847, aged 57.

Adam Seybert, Philadelphia. Died 2 May, 1825, aged 52.

George Blake, Boston. Died 6 October, 1841, aged 72.

James Savage, Boston. Died 8 March, 1873, aged 88.

Leverett Saltonstall, Salem. Died 8 May, 1845, aged 61.

25 May, 1824.

Samuel Putnam, Salem. Died 3 July, 1853, aged 85.

Levi Lincoln, Worcester. Died 29 March, 1868, aged 85.

Samuel Hoar, Concord. Died 2 November, 1856, aged 78.

24 May, 1825.

Samuel Sumner Wilde, Boston. Died 22 June, 1855, aged 84.

James Bowdoin, Boston. Died 6 March, 1833, aged 38.

Jared Sparks, Cambridge. Died 14 March, 1866, aged 76.

10 August, 1825.

Joel Roberts Poinsett, Charleston, South Carolina. Died 14 December, 1851, aged 72.

Octavius Pickering, Salem. Died 29 October, 1868, aged 77.

9 November, 1825.

John Murray Forbes, Milton. Died 14 June, 1831, aged 59.

James Luce Kingsley, New Haven. Died 31 August, 1852, aged 74.

30 May, 1826.

Washington Allston, Boston. Died 9 July, 1843, aged 63.

29 May, 1827.

Charles Folsom, Cambridge. Died 8 November, 1872, aged 77.

Thaddeus William Harris, Dorchester. Died 16 January, 1856, aged 60.

George Barrell Emerson, Boston. Died 4 March, 1881, aged 83.

Solomon Pearson Miles, Boston. Died 22 August, 1842, aged 51.

Warren Colburn, Lowell. Died 15 September, 1833, aged 40.

26 May, 1829.

Abel Lawrence Peirson, Salem. Died 6 May, 1853, aged 57.

25 May, 1830.

Gamaliel Bradford, Boston. Resigned 24 January, 1835.

10 November, 1830.

John Reed, Yarmouth. Died 25 November, 1860, aged 79.

Ezra Shaw Goodwin, Sandwich. Died 5 February, 1833, aged 45.

Robert Treat Paine, Boston.

John James Audubon, Louisiana. Died 27 January, 1851, aged 70.

25 January, 1832.

William Cranch Bond, Dorchester. Died 29 January, 1859, aged 69.

14 November, 1832.

Benjamin Daniel Greene, Boston. Died 14 October, 1862, aged 68.

28 May, 1833.

Francis Alger, Boston. Died 27 November, 1863, aged 56.

29 January, 1834.

Samuel Luther Dana, Waltham. Died 11 March, 1868, aged 72.

Benjamin Peirce, Cambridge. Resigned 11 January, 1854.

Edward Wigglesworth, Boston. Died 15 October, 1876, aged 72.

27 May, 1834.

Edward Hitchcock, Amherst. Died 27 February, 1864, aged 70.

Joshua Bates, Middlebury, Vermont. Died 14 January, 1854, aged 77.

James Hayward, Cambridge. Died 27 July, 1866, aged 80.

12 November, 1834.

Jonathan Ingersoll Bowditch, Boston.

Thomas P. Jones, Washington. Died 11 March, 1848, aged 75.

26 May, 1835.

Jasper Adams, Charleston, South Carolina. Died 25 October, 1841, aged 48.

24 May, 1836.

Thomas Sherwin, Boston. Died 23 July, 1869, aged 70.

8 November, 1837.

David Humphreys Storer, Boston.

Charles Thomas Jackson, Boston. Died 29 August, 1880, aged 75.

8 August, 1838.

Francis William Pitt Greenwood, Boston. Died 2 August, 1843, aged 46.

Augustus Allen Hayes, Roxbury.

John Barnard Swett Jackson, Boston. Died 6 January, 1879, aged 72.

14 November, 1838.

Oliver Wendell Holmes, Boston.

Martin Gay, Boston. Died 12 January, 1850, aged 46.

Joseph Hale Abbot, Boston. Died 7 April, 1873, aged 70.

Marcus Catlin, Clinton, New York. Died 11 October, 1849, aged 44.

30 January, 1839.

Joseph Lovering, Cambridge.

13 November, 1839.

Edward Reynolds, Boston.

Nicholas Tillinghast, Barre. Resigned 10 August, 1844.

29 January, 1840.

William Hickling Prescott, Boston. Died 28 January, 1859, aged 62.

Charles Storer Storrow, Boston.

26 May, 1840.

Uriah Atherton Boyden, Boston. Resigned 7 January, 1852.

19 August, 1840.

Daniel Oliver, Cambridge. Died 1 June, 1842, aged 54.

27 January, 1841.

Albert Hopkins, Williamstown. Died 25 May, 1872, aged 64.

George Bomford, Washington. Died 25 March, 1848, aged 68.

25 May, 1841.

James Englebert Teschemacher, Boston. Died 9 November, 1853, aged 63.

Augustus Addison Gould, Boston. Died 15 September, 1866, aged 61.

11 August, 1841.

James Fowle Baldwin, Boston. Died 20 May, 1862, aged 80.

Mark Hopkins, Williamstown.

10 November, 1841.

John Amory Lowell, Boston.
William Oakes, Ipswich. Died 31 July, 1848, aged 49.
Asa Gray, New York.
Edward H. Courtenay, Charlottesville, Virginia. Died 21 December, 1853, aged 50.

9 February, 1842.

William Mitchell, Nantucket. Died 19 April, 1869, aged 77.

24 May, 1842.

Nathan Appleton, Boston. Died 14 July, 1861, aged 81.
Heman Humphrey, Amherst. Died 3 April, 1861, aged 82.
Amos Binney, Boston. Died 18 February, 1847, aged 43.
Simeon Borden, Fall River. Died 28 October, 1856, aged 58.
John Lewis Russell, Salem. Died 7 January, 1873, aged 64.
Francis Cabot Lowell, Boston. Died 8 September, 1874, aged 71.
Charles Henry Davis, Cambridge. Elected Associate Fellow 27 May, 1873.
James Walker, Cambridge. Died 23 December, 1874, aged 80.
Francis Bowen, Cambridge. Resigned 13 June, 1876.

8 February, 1843.

Horatio Greenough, Florence, Italy. Died 18 December, 1852, aged 47.
Jeffries Wyman, Boston. Died 4 September, 1874, aged 60.
Francis Peabody, Salem. Died 31 October, 1867, aged 65.

30 May, 1843.

Thomas Cole, Salem. Died 24 June, 1852, aged 72.
John Harrison Blake, Boston.

9 August, 1843.

Morrill Wyman, Cambridge.

7 February, 1844.

Cornelius Conway Felton, Cambridge. Died 26 February, 1862, aged 54.
George Rapall Noyes, Cambridge. Died 3 June, 1868, aged 70.
Henry Coit Perkins, Newburyport. Died 2 February, 1873, aged 68.

13 November, 1844.

Henry Wadsworth Longfellow, Cambridge.
Samuel Cabot, Boston.
James Bicheno Francis, Lowell.

29 January, 1845.

Charles Beck, Cambridge. Died 19 March, 1866, aged 67.
Elisha Bartlett, Lowell. Died 19 July, 1855, aged 50.

26 February, 1845.

Theophilus Parsons, Boston. Resigned 4 March, 1881.
Henry Wheatland, Salem.

27 May, 1845.

Edward Tuckerman, Boston.
Samuel George Morton, Philadelphia. Died 15 May, 1851, aged 52.
Henry Darwin Rogers, Philadelphia. Elected Associate Fellow 25 January, 1865.
William Barton Rogers, Charlottesville, Virginia.

24 September, 1845.

John Hapgood Temple, Boston. Died 25 July, 1877, aged 64.
Charles Pickering, Washington. Died 17 March, 1878, aged 72.

26 May, 1846.

Henry Jacob Bigelow, Boston.

27 January, 1847.

John Bacon, Boston.

25 May, 1847.

Edward Robinson, New York. Elected Associate Fellow 11 November, 1857.
Horace Gray, Boston. Resigned.

John Clarke Lee, Salem. Died 19 November, 1877, aged 73.
Eben Norton Horsford, Cambridge.

11 August, 1847.

Samuel Atkins Eliot, Boston. Died 30 January, 1862, aged 63.
Benjamin Apthorp Gould, Cambridge.
George Phillips Bond, Cambridge. Died 17 February, 1865, aged 39.

10 November, 1847.

William Henry Swift, Washington. Resigned 10 May, 1876.
Abbot Lawrence, Boston. Died 18 August, 1855, aged 62.
George Putnam, Roxbury. Resigned 6 January, 1872.
Charles Greely Loring, Boston. Died 8 October, 1867, aged 73.

26 January, 1848.

Charles Jackson, Boston. Died 30 July, 1871, aged 56.

10 August, 1848.

Henry Ingersoll Bowditch, Boston.
Epes Sargent Dixwell, Cambridge.
Edward Clark Cabot, Boston. Resigned 9 May, 1877.

8 November, 1848.

Jonathan Mason Warren, Boston. Died 19 August, 1867, aged 56.

29 May, 1849.

Charles Baker Adams, Amherst. Died 19 January, 1853, aged 39.

8 August, 1849.

Robert Charles Winthrop, Boston.
William Francis Channing, Boston.

13 February, 1850.

Henry Lawrence Eustis, Cambridge.
Samuel Leonard Abbot, Boston.

28 May, 1850.

Thomas Tracy Bouvé, Boston.
Jonathan Patten Hall, Boston. Died 6 March, 1866, aged 66.

14 August, 1850.

Josiah Dwight Whitney, Boston. Resigned 27 January, 1875.

29 January, 1851.

William Jenks, Boston. Died 13 November, 1866, aged 87.

28 May, 1851.

John Pitkin Norton, New Haven. Died 5 September, 1852, aged 30.

13 August, 1851.

Waldo Irving Burnett, Boston. Died 1 July, 1854, aged 27.
Nathaniel Bradstreet Shurtleff, Boston. Died 17 October, 1874, aged 64.

10 August, 1852.

Samuel Kneeland, Boston.
George Martin Lane, Cambridge. Resigned 25 May, 1873.

10 November, 1852.

William Prescott Dexter, Brookline.

1 February, 1853.

Josiah Parsons Cooke, Cambridge.
Joel Parker, Cambridge. Died 17 August, 1875, aged 80.

31 May, 1853.

William Raymond Lee, Roxbury.

28 September, 1853.

Joseph Winlock, Cambridge. Died 11 June, 1875, aged 49.
Thomas Hill, Waltham. Elected Associate Fellow 25 May, 1876.

11 October, 1853.

Samuel Parkman, Boston. Died 15 December, 1854, aged 38.

Benjamin Eddy Cotting, Roxbury.

8 November, 1854.

Silas Durkee, Boston. Died 17 July, 1878; aged 79.

Benjamin Robbins Curtis, Boston. Died 15 September, 1874, aged 64.

Rufus Choate, Boston. Died 13 July, 1859, aged 59.

Charles Eliot Ware, Boston.

Ephraim Peabody, Boston. Died 28 November, 1856, aged 49.

Thomas Mayo Brewer, Boston. Died 23 January, 1880, aged 65.

31 January, 1855.

George Livermore, Cambridge. Died 30 August, 1865, aged 56.

29 May, 1855.

Francis Parkman, Boston.

14 November, 1855.

John Chipman Gray, Boston. Died 3 March, 1881, aged 87.

James Russell Lowell, Cambridge.

William Augustus Stearns, Amherst. Died 8 June, 1876, aged 71.

Francis James Child, Cambridge.

Albert Nicholas Arnold, Newton. Elected Associate Fellow 10 November, 1875.

Richard Saltonstall Greenough, Boston. Elected Associate Fellow 30 May, 1876.

27 May, 1856.

Thomas Greaves Cary, Boston. Died 3 July, 1859, aged 67.

George Edward Ellis, Charlestown.

John Benjamin Henck, Boston.

Charles James Sprague, Boston.

12 November, 1856.

Henry Warren Torrey, Cambridge.

Nathaniel Langdon Frothingham, Boston. Died 4 April, 1870, aged 76.

Benjamin Apthorp Gould, Boston. Died 24 October, 1859, aged 72.

Evangelinus Apostolides Sophocles, Cambridge.

Christian Heinrich Friedrich Peters, Cambridge. Elected Associate Fellow 13 November, 1867.

Henry James Clark, Cambridge. Elected Associate Fellow 24 May, 1870.

28 January, 1857.

John Lothrop Motley, Boston. Died 29 May, 1877, aged 63.

Charles Francis Adams, Quincy.

George Sewall Boutwell, Groton.

26 May, 1857.

John Daniel Runkle, Cambridge.

David Friedrich Weinland, Cambridge.

Moses Gerry Farmer, Salem.

Charles Gideon Putnam, Boston. Died 5 February, 1875, aged 69.

11 November, 1857.

Ezekiel Brown Elliott, Boston. Elected Associate Fellow 9 January, 1878.

Francis Humphreys Storer, Boston.

William Turell Andrews, Boston. Died 24 November, 1879, aged 84.

Charles William Eliot, Cambridge.

25 May, 1858.

Thomas Edwards Clark, Williamstown.

Horatio Robinson Storer, Boston.

Henry Bryant, Boston. Died 31 January, 1867, aged 46.

10 November, 1858.

Luther V. Bell, Charlestown. Died 11 February, 1862, aged 55.

Chandler Robbins, Boston.

Benjamin Peirce, Cambridge. Died 6 October, 1880, aged 71.

26 January, 1859.

William Watson Goodwin, Cambridge.

24 May, 1859.

John Henry Clifford, New Bedford. Died 2 January, 1876, aged 66.
Emory Washburn, Cambridge. Died 18 March, 1877, aged 77.

9 November, 1859.

Calvin Ellis, Boston.
Theodore Lyman, Brookline.
Edward Samuel Ritchie, Boston.

25 January, 1860.

Chauncey Wright, Cambridge. Died 12 September, 1875, aged 44.
Simon Newcomb, Cambridge. Elected Associate Fellow 24 May, 1870.

14 November, 1860.

Ephraim Whitman Gurney, Cambridge.
Charles Eliot Norton, Cambridge.
Horatio Balch Hackett, Newton. Died 2 November, 1875, aged 66.

30 January, 1861.

James Edward Oliver, Lynn. Elected Associate Fellow 27 May, 1873.

28 May, 1861.

Andrew Preston Peabody, Cambridge.
William Ferrel, Cambridge. Elected Associate Fellow 14 March, 1877.

13 November, 1861.

Jules Marcou, Cambridge.
Ezra Abbot, Cambridge.
Truman Henry Safford, Cambridge. Elected Associate Fellow 24 May, 1870.
George Tyler Bigelow, Boston. Died 12 April, 1878, aged 67.
Benjamin Franklin Thomas, Boston. Died 27 September, 1878, aged 65.

29 January, 1862.

John Dean, Boston.
Alvan Clark, Cambridge.
John Bernard Fitzpatrick, Boston. Died 13 February, 1866, aged 53.

10 March, 1862.

James Mills Peirce, Cambridge.

12 November, 1862.

Cyrus Mores Warren, Boston.
Alexander Emmanuel Rodolph Agassiz, Cambridge.
William Pitt Greenwood Bartlett, Cambridge. Died 13 January, 1865, aged 28.
George Mary Searle, Brookline. Elected Associate Fellow 30 May, 1876.

28 January, 1863.

Henry Larcom Abbot, Cambridge. Elected Associate Fellow 30 May, 1876.
William Wetmore Story, Boston. Elected Associate Fellow 27 May, 1873.

11 November, 1863.

Edward Jarvis, Dorchester.

27 January, 1864.

Ralph Waldo Emerson, Concord.
Richard Henry Dana, Cambridge.

9 February, 1864.

Edward Pearce, Cambridge.
William Watson, Cambridge.

24 May, 1864.

Jabez Baxter Upham, Boston.

25 January, 1865.

Frederick Ward Putnam, Salem.

30 May, 1865.

John Eugene Tyler, Somerville. Died 9 March, 1878, aged 58.
Edward Hammond Clarke, Boston. Died 30 November, 1877, aged 57.
Edward Everett Hale, Boston.
George Bemis, Boston. Died 5 January, 1878, aged 61.
Charles Sumner, Boston. Died 11 March, 1874, aged 63.

8 November, 1865.

Samuel Eliot, Boston.
George William Hill, Cambridge. Elected Associate Fellow 23 May, 1873.

31 January, 1866.

Erastus Brigham Bigelow, Boston. Died 6 December, 1879, aged 65.
Henry Mitchell, Needham.

29 May, 1866.

Nathaniel Thayer, Boston.
William Parsons Atkinson, Cambridge.
Horace Gray. Boston.
Stephen Preston Ruggles, Boston. Died 28 May, 1880, aged 71.

14 November, 1866.

James Davenport Whelpley, Boston. Died 15 April, 1872, aged 55.
Henry Willard Williams, Boston.
John Montgomery Batchelder, Cambridge.
William Gray, Boston.
James Clarke White, Boston.
James Elliot Cabot, Brookline.
William Robert Ware, Boston.
Frederick Henry Hedge, Brookline. Resigned 9 May, 1878.
Charles Deane, Cambridge.

30 January, 1867.

Gustavus Hay, Boston.
Richard Manning Hodges, Boston.
Charles Sanders Peirce, Cambridge. Elected Associate Fellow 9 January, 1878.

28 May, 1867.

Charles Édouard Brown-Séquard, Cambridge. Elected Associate Fellow 27 May, 1873.
John Rodgers, Charlestown. Elected Associate Fellow 10 October, 1877.

13 November, 1867.

Edward Charles Pickering, Boston.
James Mason Crafts, Boston.

26 May, 1868.

Samuel Hubbard Scudder, Cambridge.
John Lord Hayes, Cambridge.
William Smith Clark, Amherst.

11 November, 1868.

Nathaniel Ellis Atwood, Provincetown.
Hermann August Hagen, Cambridge.
Horace Mann, Cambridge. Died 11 November, 1868, aged 24.
Alpheus Spring Packard, Salem. Elected Associate Fellow 27 May, 1879.
Edmund Quincy, Dedham. Died 17 May, 1877, aged 69.

25 May, 1869.

William Tufts Brigham, Boston.
Algernon Coolidge, Boston.
Alfred Perkins Rockwell, Boston.
Alpheus Hyatt, Salem.
Edward Sylvester Morse, Salem.

10 November, 1869.

Thomas William Parsons, Boston.
James Munson Barnard, Boston.
Henry Laurens Whiting, Tisbury.
Nathaniel Southgate Shaler, Cambridge.

24 May, 1870.

Charles Callahan Perkins, Boston.
Nathaniel Holmes, Cambridge. Elected Associate Fellow 30 May, 1876.
Raphael Pumpelly, Cambridge. Elected Associate Fellow 9 January, 1878.
George Derby, Boston. Died 20 June, 1874, aged 55.

9 November, 1870.

Elbridge Jefferson Cutler, Cambridge. Died 27 December, 1870, aged 39.
Edward James Young, Cambridge.
Christopher Columbus Langdell, Cambridge.

14 February, 1871.

Charles Francis Adams, Boston.
Charles Carroll Everett, Cambridge.
William Everett, Cambridge.

Henry William Paine, Cambridge.
John Greenleaf Whittier, Amesbury.
Ferdinand Bôcher, Boston. Resigned, 1873.

30 May, 1871.

Louis François de Pourtalès, Cambridge. Died 18 July, 1880, aged 58.
Robert Amory, Brookline.

8 November, 1871.

Henry Gardner Denny, Boston.
John Trowbridge, Cambridge.
Joel Asaph Allen, Cambridge.
William Henry Pettee, Cambridge.
John Knowles Paine, Cambridge. Resigned 1 May, 1878.
Edwin Pliny Seaver, Cambridge.

12 December, 1871.

Robert William Hooper, Boston.
John Bulkley Perry, Cambridge. Died 3 October, 1872, aged 52.
Stephen Paschall Sharples, Cambridge.
George Rumford Baldwin, Woburn.

31 January, 1872.

Charles Franklin Dunbar, Cambridge.
William Augustus Rogers, Cambridge.

28 May, 1872.

Horatio Hollis Hunnewell, Wellesley.
Henry Pickering Bowditch, Boston.

27 November, 1872.

William Ripley Nichols, Boston.
Charles Loring Jackson, Cambridge.
Charles Otis Boutelle, Washington.
John Mudge Merrick, Boston. Died 25 February, 1879, aged 40.
Nicholas Saint-John Green, Cambridge. Died 8 September, 1876, aged 46.

12 November, 1873.

George Stillman Hillard, Boston. Resigned 28 May, 1876.

28 January, 1874.

George Lincoln Goodale. Cambridge.

10 March, 1874.

Ebenezer Rockwood Hoar, Concord. Resigned 17 December, 1877.

26 May, 1874.

Francis Wharton, Cambridge. Resigned 10 May, 1878.

11 November, 1874.

Charles Hallett Wing, Boston.
John McCrady, Cambridge.
William Gilson Farlow, Cambridge.
Sereno Watson, Cambridge.

27 January, 1875.

Henry Barker Hill, Cambridge.
James Bradstreet Greenough, Cambridge. Resigned 10 May, 1876.
William James, Cambridge.

10 November, 1875.

Hiram Francis Mills, Lawrence.
Robert Thaxter Edes, Boston.
Ira Remsen, Williamstown.
Henry Adams, Boston.

26 January, 1876.

Charles Edward Hamlin, Cambridge.
Edwin Laurence Godkin, Cambridge.
Thomas Dwight, Boston.

12 April, 1876.

John Langdon Sibley, Cambridge.

30 May, 1876.

William Edward Story, Somerville.
Bennett Hubbard Nash, Boston.

14 March, 1877.

Alexander Graham Bell, Boston.

29 May, 1877.

Leopold Trouvelot, Cambridge.

10 October, 1877.

Arthur Searle, Cambridge.
Charles Robert Cross, Boston.
Amos Emerson Dolbear, Medford.
George Cheyne Shattuck, Boston.
Francis Minot, Boston.
Charles Smith Bradley, Cambridge.
Oliver Wendell Holmes, Boston.
John Lowell, Boston.
James Bradley Thayer, Cambridge.

9 January, 1878.

George Bassett Clark, Cambridge.
Thomas Potts James, Cambridge.
John Fiske, Cambridge. Resigned 17 November, 1880.
Charles Greely Loring, Boston.

13 March, 1878.

Edward Burgess, Boston.
James Jackson Putnam, Boston.
John Collins Warren, Boston.
Phillips Brooks, Boston.
John Williams White, Cambridge.
Justin Winsor, Cambridge.

28 May, 1878.

William Elwood Byerly, Cambridge.
Charles Follen Folsom, Boston.

9 October, 1878.

James Barr Ames, Cambridge.
John Chipman Gray, Boston.
Erasmus Darwin Leavitt, Cambridge.
John Phillips Reynolds, Boston.
Charles Sprague Sargent, Brookline.

13 November, 1878.

William Sumner Appleton, Boston.
Henry Cabot Lodge, Boston.
Henry Hobson Richardson, Brookline.
Joseph Samuel Ropes, Boston.

12 March, 1879.

Edward Atkinson, Boston.
James Freeman Clarke, Boston.
Frank Winthrop Draper, Boston.
Alfred Hosmer, Watertown.
Robert Hallowell Richards, Boston.

27 May, 1879.

William Lambert Richardson, Boston.

8 October, 1879.

Frank Austin Gooch, Cambridge.
Nathaniel Dana Carlile Hodges, Cambridge.
Edward Stickney Wood, Cambridge.

25 May, 1880.

John Rayner Edmands, Cambridge.
Henry Purkitt Kidder, Boston.

13 October, 1880.

Henry Williamson Haynes, Boston.

24 May, 1881.

Alvan Graham Clark, Cambridge.
Francis Blake, Auburndale.
Lucien Carr, Cambridge.

12 October, 1881.

Clarence John Blake, Boston.
Thomas Gaffield, Boston.
Frederic Walker Lincoln, Boston.
William Otis Crosby, Boston.
William Harmon Niles, Cambridge.
Charles Rockwell Lanman, Cambridge.
John Davis Long, Boston.
John Cummings, Woburn.

ASSOCIATE FELLOWS.

9 August, 1809.

Parker Cleaveland, Brunswick. Died 15 October, 1858, aged 78.

William Cranch, Washington. Died 1 September, 1855, aged 86.

14 November, 1810.

John Langdon Sullivan, Boston. Died 9 February, 1865, aged 88.

28 May, 1811.

Reuben Dimond Mussey, Salem.

18 August, 1813.

Jeremiah Day, New Haven. Died 22 August, 1867, aged 93.

25 January, 1815.

Benjamin Silliman, New Haven. Died 22 November, 1864, aged 85.

14 August, 1816.

Joseph Green Cogswell, Northampton.

26 May, 1818.

Chester Dewey, Williamstown. Died 15 December, 1867, aged 83.

12 November, 1823.

Thomas Nuttall, Cambridge. Died 10 September, 1859, aged 73.

18 February, 1824.

Robert Hare, Philadelphia. Died 15 May, 1858, aged 77.

10 August, 1825.

Manuel Moreno, Buenos Aires. Died 18 December, 1857, aged 77.

30 May, 1826.

Charles Davies, West Point, New York. Died 18 September, 1876, aged 78.

10 November, 1830.

Francis Lieber, Boston. Died 2 October, 1872, aged 72.

Francis Wayland, Providence. Died 30 September, 1865, aged 69.

24 May, 1831.

Henry James Anderson, New York. Died 19 October, 1875, aged 76.

James Renwick, New York. Died 12 January, 1863, aged 70.

Alonzo Potter, Boston. Died 4 July, 1865, aged 64.

William Sweetser, Boston. Died 14 October, 1875, aged 78.

25 January, 1832.

Eugenius Nulty, Philadelphia. Died 3 July, 1871, aged 82.

Theodore Strong, New Brunswick, New Jersey. Died 1 February, 1869, aged 78.

29 January, 1834.

Sylvanus Thayer, Boston.

Robert Maskell Patterson, Charlottesville, Virginia. Died 5 September, 1854, aged 67.

26 May, 1835.

Francis Boott, London. Died 25 December, 1863, aged 71.

14 November, 1838.

Joseph Roby, Boston. Died 3 June, 1860, aged 51.

Charles Gill, Flushing, New York. Dead.

Charles Avery, Clinton, New York.

26 May, 1840.

Joseph Henry, Princeton, New Jersey. Died 13 May, 1878, aged 78.

19 August, 1840.

Charles Morris, Washington. Died 27 January, 1856, aged 71.

Charles Wilkes, Washington. Died 8 February, 1877, aged 76.

11 November, 1840.

Charles Cramer, St. Petersburg.

11 August, 1841.

Joseph Gilbert Totten, Washington. Died 22 April, 1864, aged 75.

Richard Delafield, West Point, New York. Died 4 November, 1873, aged 75.

10 November, 1841.

John Torrey, New York. Died 10 March, 1873, aged 76.

9 February, 1842.

Sears Cook Walker, Philadelphia. Died 30 January, 1853, aged 47.

10 August, 1842.

Charles Grafton Page, Washington. Died 5 May, 1868, aged 56.

30 May, 1843.

Angel Calderon de la Barca, Madrid. Died 31 May, 1861, aged 70.

13 November, 1844.

William Fitzwilliam Owen, London. Dead.

Alpheus Spring Packard, Brunswick, Maine.

William Smyth, Brunswick, Maine. Died 3 April, 1868, aged 71.

29 January, 1845.

Theodore Dwight Woolsey, New Haven.

26 February, 1845.

William Starling Sullivant, Columbus, Ohio. Died 30 April, 1873, aged 70.

27 May, 1845.

Horace Mann, Boston. Died 2 August, 1859, aged 63.

Alexander Dallas Bache, Philadelphia. Died 17 February, 1867, aged 60.

James Duncan Graham, Washington. Died 28 December, 1865, aged 66.

John James Abert, Washington. Died 27 January, 1863, aged 78.

George Talcott, Washington.

Jacob Whitman Bailey, West Point, New York. Died 27 February, 1857, aged 45.

William Holmes Chambers Bartlett, West Point, New York.

William Charles Redfield, New York. Died 12 February, 1857, aged 67.

Elias Loomis, New York.

John Edwards Holbrook, Charleston, South Carolina. Died 8 September, 1871, aged 74.

John Bachman, Charleston, South Carolina. Died 15 February, 1874, aged 84.

26 November, 1845.

James Dwight Dana, New Haven.

12 August, 1846.

Stephen Pearl Andrews, Boston.

George Engelmann, St. Louis.

25 May, 1847.

Charles Coffin Jewett, Washington.

10 November, 1847.

Ormsby McKnight Mitchel, Cincinnati. Died 30 October, 1862, aged 52.

26 January, 1848.

Édouard Desor, Neufchâtel, Switzerland.

Spencer Fullerton Baird, Carlisle, Pennsylvania.

30 May, 1848.

Joseph Leidy, Philadelphia.
Maria Mitchell, Poughkeepsie, New York.

10 August, 1848.

John Lawrence Le Conte, New York.
James Hall, Albany.

8 November, 1848.

Edward Elbridge Salisbury, New Haven.

31 January, 1849.

Arnold Henry Guyot, Cambridge.

29 May, 1849.

Charles Upham Shepard, Amherst.
William Helmsley Emory, Washington.

13 November, 1849.

Wolcott Gibbs, New York.
Samuel Finley Breese Morse, Poughkeepsie, New York. Died 2 April, 1872, aged 80.

13 February, 1850.

Samuel Stehman Haldeman, Columbia, Pennsylvania. Died 10 September, 1880, aged 68.

14 August, 1850.

John Charles Fremont, Mariposa, California.
Stephen Alexander, Princeton, New Jersey.
Joseph Stillman Hubbard, Washington. Died 16 August, 1863, aged 39.

13 November, 1850.

Alexis Caswell, Providence, Rhode Island. Died 8 January, 1877, aged 77.
William Chauvenet, Annapolis, Maryland. Died 13 December, 1870, aged 50.

29 January, 1851.

George Perkins Marsh, Burlington, Vermont.
William Augustus Norton, Providence, Rhode Island.
Charles Bricket Haddock, Hanover, New Hampshire. Died 15 January, 1861, aged 64.

28 May, 1851.

Benjamin Silliman, New Haven.

13 August, 1851.

John Huntingdon Crane Coffin, Washington.

12 November, 1851.

Thomas Sterry Hunt, Montreal.

11 December, 1855.

Moses Ashley Curtis, Society Hill, South Carolina. Died 10 April, 1872, aged 63.
Charles Wilkins Short, Louisville, Kentucky. Died 7 March, 1863, aged 68.
Jared Potter Kirtland, Cleveland, Ohio. Died 10 December, 1877, aged 84.
John Call Dalton, New York.
Dennis Hart Mahan, West Point, New York. Died 16 September, 1871, aged 69.
Hiram Powers, Florence, Italy. Died 27 June, 1873, aged 67.
Thomas Crawford, Rome, Italy. Died 10 October, 1857, aged 43.
William Cullen Bryant, New York. Died 12 June, 1878, aged 83.
Washington Irving, Tarrytown, New York. Died 28 November, 1859, aged 76.

9 December, 1856.

Laurens Perseus Hickok, Schenectady, New York.
George Bacon Wood, Philadelphia. Died 30 March, 1879, aged 82.
Isaac Hays, Philadelphia. Died 12 April, 1879, aged 82.

11 November, 1857.

Saint Julien Ravanel, Charleston, South Carolina.
Edward Robinson, New York. Died 27 January 1863, aged 68.

26 January, 1859.

Sir William Edmond Logan, Montreal. Died 22 June, 1875, aged 77.

9 November, 1859.

Samuel Greene Arnold, Providence, Rhode Island. Died 12 February, 1880, aged 58.

Edward Bissell Hunt, Brattleborough, Vermont. Died 2 October, 1863, aged 41.

George Clinton Swallow, Columbia, Missouri.

14 November, 1860.

Frederick Augustus Porter Barnard, Oxford, Mississippi.

William Dwight Whitney, New Haven.

John Le Conte, Columbia, South Carolina.

John William Dawson, Montreal.

13 November, 1861.

James Melville Gilliss, Washington. Died 9 February, 1865, aged 53.

John Morse Ordway, Manchester, New Hampshire.

James Hadley, New Haven. Died 14 November, 1872, aged 51.

Francis Simmons Holmes, Charleston, South Carolina.

27 May, 1862.

Hubert Anson Newton, New Haven.

28 January, 1863.

Andrew Atkinson Humphreys, Washington.

11 November, 1863.

Henry Charles Carey, Philadelphia. Died 13 October, 1879, aged 85.

George Bancroft, New York.

John Pendleton Kennedy, Baltimore. Died 18 August, 1870, aged 74.

Frederic Edwin Church, New York.

27 January, 1864.

John Peter Lesley, Philadelphia.

9 February, 1864.

George Gordon Meade, New York. Died 6 November, 1872, aged 56.

Ogden Nicholas Rood, New York.

25 January, 1865.

Henry Darwin Rogers, Glasgow. Died 29 May, 1866, aged 57.

30 May, 1865.

Fielding Bradford Meek, Washington. Died 21 December, 1876, aged 59.

John William Draper, New York.

Tayler Lewis, Schenectady, New York. Died 11 May, 1877, aged 75.

Silas Weir Mitchell, Philadelphia.

Samuel Gilman Brown, Hanover, New Hampshire.

Daniel Raynes Goodwin, Philadelphia.

8 November, 1865.

Lewis Morris Rutherfurd, New York.

31 January, 1866.

Barnas Sears, Providence, Rhode Island. Died 6 July, 1880, aged 77.

Asahel Clark Kendrick, Rochester, New York.

29 May, 1866.

Noah Porter, New Haven.

Ira Perley, Concord, New Hampshire. Died 26 February, 1874, aged 74.

Alvan Wentworth Chapman, Appalachicola, Florida.

14 November, 1866.

Isaac Ray, Providence, Rhode Island.

28 May, 1867.

John Lawrence Smith, Louisville, Kentucky.

Horace Binney, Philadelphia. Died 12 August, 1875, aged 95.

Daniel Lord, New York. Died 4 March, 1868, aged 73.

13 November, 1867.

Christian Heinrich Friedrich Peters, Clinton, New York.

10 December, 1867.

Rowland Gibson Hazard, Peace Dale, Rhode Island.

26 May, 1868.

Andrew Dickson White, Ithaca, New York.
James Burrill Angell, Burlington, Vermont.
Lewis Henry Morgan, Rochester, New York.

24 May, 1870.

Simon Newcomb, Washington.
Truman Henry Safford, Chicago.
Henry James Clark, Lexington, Kentucky. Died 1 July, 1873, aged 47.

9 November, 1870.

Henry Charles Lea, Philadelphia.

14 February, 1871.

George Jarvis Brush, New Haven.
Stephen Thayer Olney, Providence, Rhode Island. Died 27 July, 1878, aged 66.
Jeremiah Smith, Dover, New Hampshire.

30 May, 1871.

Samuel William Johnson, New Haven.
Charles Augustus Young, Hanover, New Hampshire.
Leo Lesquereux, Columbus, Ohio.

28 May, 1872.

William Theodore Roepper, Bethlehem, Pennsylvania. Died 11 March, 1880, aged 70.

27 May, 1873.

Charles Henry Davis, Norfolk, Virginia. Died 18 February, 1877, aged 70.
Charles Édouard Brown-Séquard, Paris. Elected Foreign Honorary Member, 9 February, 1881.
William Wetmore Story, Rome, Italy.
James Edward Oliver, Ithaca, New York.
George William Hill, Nyack Turnpike, New York.

11 November, 1874.

Julius Erasmus Hilgard, Washington.
William Petit Trowbridge, New Haven.
William Alexander Hammond, New York.
James Hammond Trumbull, Hartford, Connecticut.
James McCosh, Princeton, New Jersey.

10 November, 1875.

Alfred Marshall Mayer, Hoboken, New Jersey.
Frederick Augustus Genth, Philadelphia.
Joseph Le Conte, Oakland, California.
Othniel Charles Marsh, New Haven.
Daniel Coit Gilman, Baltimore.
William Sellers, Philadelphia.
Albert Nicholas Arnold, Chicago.

12 April, 1876.

Henry Augustus Rowland, Baltimore.

30 May, 1876.

Thomas Hill, Portland, Maine.
George Mary Searle, New York.
Henry Larcom Abbot, Willet's Point, New York.
Nathaniel Holmes, St. Louis.
Richard Saltonstall Greenough, Florence, Italy

14 March, 1877.

Jeremiah Lewis Diman, Providence, Rhode Island. Died 3 February, 1881, aged 49.
William Ferrel, Washington.

10 October, 1877.

John Rodgers, Washington.

9 January, 1878.

Ezekiel Brown Elliott, Washington.
Raphael Pumpelly, Owego, New York.
Charles Sanders Peirce, New York.

12 March, 1879.

Asaph Hall, Washington.

27 May, 1879.

James Craig Watson, Madison, Wisconsin. Died 23 November, 1880, aged 42.

Alpheus Spring Packard, Providence, Rhode Island.

11 February, 1880.

Josiah Willard Gibbs, New Haven.

Clarence King, Washington.

24 May, 1881.

Fordyce Barker, New York.

John Shaw Billings, Washington.

Jacob M. DaCosta, Philadelphia.

Alfred Stillé, Philadelphia.

Manning Ferguson Force, Cincinnati.

William Graham Sumner, New Haven.

12 October, 1881.

Henry Draper, New York.

FOREIGN HONORARY MEMBERS.

31 January, 1781.

César Anne de la Luzerne, Paris. Died 14 September, 1791, aged 50.

François, Marquis de Barbé-Marbois, Paris. Died 12 January, 1837, aged 91.

22 August, 1781.

Jean le Rond d'Alembert, Paris. Died 29 October, 1783, aged 65.

François Jean, Marquis de Chastellux, Paris. Died 28 October, 1788, aged 54.

Antoine Court de Gébelin, Paris. Died 10 May, 1784, aged 59.

Joseph Jérome le François de Lalande, Paris. Died 4 April, 1807, aged 74.

Pehr Wilhelm Wargentin, Stockholm. Died 13 December, 1783, aged 66.

30 January, 1782.

George Louis Leclerc, Comte de Buffon, Paris. Died 16 April, 1788, aged 80.

Leonhard Euler, St. Petersburg. Died 7 September, 1783, aged 76.

Richard Price, London. Died 19 April, 1791, aged 68.

Joseph Priestley, Birmingham, England. Died 6 February, 1804, aged 70.

28 May, 1782.

Thomas Brand Hollis, London. Died 9 September, 1804, aged 84.

13 November, 1782.

Comte de Granchain. Brest. Died 19 June, 1805.

29 January, 1783.

Edme Sébastien Jeaurat, Paris. Died 7 March, 1803, aged 77.

25 May, 1784.

Friherre Samuel Gustaf Hermelin, Stockholm. Died 4 March, 1820, aged 75.

26 January, 1785.

Petter Jonas Bergius, Stockholm. Died 10 July, 1790, aged 60.

Marie Jean Paul Roch Yves Gilbert Motier, Marquis de Lafayette, Paris. Died 20 May, 1834, aged 76.

24 August, 1785.

Henry Moyes, London. Died 11 December, 1807, aged 57.

30 May, 1786.

Carlo Ottavio Conte di Castiglioni, Tuscany. Dead in 1833.

23 August, 1786.

Jean Feron, Paris. Dead in 1833.

30 April, 1788.

Sir Joseph Banks, Baronet, London. Died 19 June, 1820, aged 77.

Nevil Maskelyne, Greenwich. Died 9 February, 1811, aged 78.

Thomas Hornsby, Oxford. Died 11 April, 1810, aged 76.

Richard Watson, Calgarth Park. Died 4 July, 1816, aged 79.

Sir Frederick William Herschel, Slough. Died 25 August, 1822, aged 83.

Jean Dominique, Comte de Cassini, Paris. Died 18 October, 1845, aged 97.

Johann Jacob Hemmer, Mannheim. Died 3 May, 1790, aged 57.

20 August, 1788.

Charles Hutton, Woolwich. Died 27 January, 1823, aged 85.

John Coakley Lettsom, London. Died 1 November, 1815, aged 70.

Jonathan Stokes, Kidderminster. Died 30 April, 1831, aged 76.

28 January, 1789.

John Haygarth, Chester. Died 10 June, 1827, aged 87.

Jean Pierre Brissot de Warville, Paris. Died 30 October, 1793, aged 39.

29 May, 1789.

Pedro de Luxan, Duque de Almodóvar, Spain. Died July, 1794, aged 66.

Antoine Marie Cerisier, Paris. Died 1 July, 1828, aged 79.

Marqués de Santa Cruz, Spain. Dead in 1833.

Charles William Frederick Dumas, The Hague. Dead in 1793.

Edmund Jennings, London. Dead in 1833.

Jean Luzac, Leyden. Died 12 January, 1807, aged 60.

Archibald Maclaine, The Hague. Died 25 November, 1804, aged 82.

Frederik Willem Pestel, Leyden. Died 16 October, 1805, aged 81.

Benjamin Thompson, Graf von Rumford, Munich. Died 21 August, 1814, aged 61.

2 December, 1789.

Sir Charles Blagden, London. Died 26 March, 1820, aged 71.

Richard Kirwan, London. Died 22 June, 1812, aged 76.

Thomas Percival, Manchester. Died 30 August, 1804, aged 63.

27 January, 1790.

Johann Wilhelm Karl Adolph, Freiherr von Hüpsch, Cologne. Died 1 January, 1805, aged 78.

Grímur Jónsson Thorkelin, Copenhagen. Died 4 March, 1829, aged 66.

John Howard, London. Died 20 January, 1790, aged 63.

Robert Young, London. Dead in 1855.

25 August, 1790.

George Erving, London. Died 1806, aged 70.

10 November, 1790.

Joseph Philippe de l'Etombe, France. Dead in 1833.

24 August, 1791.

Benjamin West, London. Died 10 March, 1820, aged 82.

John Singleton Copley, London. Died 9 September, 1815, aged 78.

John Cranch, London. Dead in 1833.

29 May, 1792.

Sir William Hamilton, London. Died 6 April, 1803, aged 73.

Marie Jean Antoine Nicolas Caritat, Marquis de Condorcet, Paris. Died 28 March, 1794, aged 50.

27 May, 1794.

Louis Valentin, San Domingo. Died 1829, aged 71.

Johann Friedrich Blumenbach, Göttingen. Died 22 January, 1840, aged 87.

25 January, 1797.

Sir John Sinclair, Baronet, Ulbster, Scotland. Died 21 January, 1835, aged 81.

30 May, 1797.

Edward Bancroft, London. Died 8 September, 1821, aged 77.

22 August, 1798.

Mather Brown, London. Died 1 June, 1831.

Franz Xaver, Freiherr von Zach, Seeberg. Died 2 September, 1832, aged 78.

26 May, 1800.

William Falconer, Bath. Died 1824, aged 81.

25 May, 1802.

Edward Jenner, Berkeley, England. Died 26 January, 1823, aged 73.

24 May, 1803.

Bernard Edward Howard, Duke of Norfolk, London. Died 16 March, 1842, aged 76.

William Petty, Marquis of Lansdowne. Died 7 May, 1805, aged 68.

29 May, 1804.

Friherre Gustaf von Paijkull, Upsal. Died 28 January, 1826, aged 68.

13 February, 1805.

Olof Swartz, Stockholm. Died 19 September, 1818, aged 57.

9 August, 1809.

Cornelis De Gyzelaer, Leyden. Died 29 May, 1815, aged 64.

19 August, 1812.

Charles Etter, St. Petersburg. Dead in 1850.

11 November, 1812.

Gotthelf Friedrich Fischer von Waldheim, Moscow. Died 18 October, 1853, aged 82.

Nicolaus von Fuss, St. Petersburg. Died 4 January, 1826, aged 70.

Friedrich Theodor Schubert, St. Petersburg. Died 21 October, 1825, aged 66.

25 May, 1813.

Abraham Rees, London. Died 9 June, 1825, aged 82.

25 January, 1815.

José Francisco Correa de Serra, Lisbon. Died 11 September, 1823, aged 72.

23 August, 1815.

Jean Antoine Fabre, Brignoles. Died 31 January, 1834, aged 85.

13 August, 1817.

Dugald Stewart, Edinburgh. Died 11 June, 1828, aged 74.

26 May, 1818.

Sir Benjamin Hobhouse, England. Died 15 August, 1831, aged 74.

30 January, 1822.

Barthold Georg, Freiherr von Niebuhr, Bonn. Died 2 January, 1831, aged 54.

Pierre Simon, Marquis de La Place, Paris. Died 5 March, 1827, aged 77.

Baron Georges Léopold Christian Frédéric Dagobert Cuvier. Died 13 May, 1832, aged 62.

Claude Louis, Comte Berthollet, Paris. Died 6 November, 1822, aged 73.

Sir Humphry Davy, London. Died 29 March, 1829, aged 50.

William Hyde Wollaston, London. Died 22 December, 1828, aged 62.

Heinrich Wilhelm Matthias Olbers, Bremen. Died 2 March, 1840, aged 81.

Carl Friedrich Gauss, Göttingen. Died 23 February, 1855, aged 77.

Karl Wilhelm, Freiherr von Humboldt, Berlin. Died 8 April, 1835, aged 67.

Friedrich Heinrich Alexander, Freiherr von Humboldt, Berlin. Died 6 May, 1859, aged 89.

21 August, 1822.

John Pond, Greenwich. Died 7 September, 1836, aged 69.

Thomas Young, London. Died 10 May, 1829, aged 55.

John Brinkley, Dublin. Died 14 September, 1835, aged 72.

Sir David Brewster, Edinburgh. Died 10 February, 1868, aged 86.

Friherre Jöns Jacob Berzelius, Stockholm. Died 7 August, 1848, aged 68.

Jean Baptiste Biot, Paris. Died 3 February, 1862, aged 87.

Johann Tobias Bürg, Vienna. Died 25 November, 1834, aged 67.

Johann Karl Burckhardt, Paris. Died 21 June, 1825, aged 52.

Jean Baptiste Joseph Delambre, Paris. Died 19 August, 1822, aged 72.

Siméon Denis Poisson, Paris. Died 25 April, 1840, aged 58.

Bernhard August, Freiherr von Lindenau, Gotha. Died 21 May, 1854, aged 73.

27 May, 1823.

Samuel Parkes, London. Died 23 December, 1825, aged 64.

12 November, 1823.

Sir William Jackson Hooker, Glasgow. Died 12 August, 1865, aged 80.

24 May, 1825.

William Buckland, London. Died 14 August, 1856, aged 72.

Henry James Brooke, London. Died 26 June, 1857, aged 86.

10 August, 1825.

Johann Gottfried Eichhorn, Göttingen. Died 25 June, 1827, aged 74.

30 January, 1828.

Julius, Freiherr von Wallenstein, Russia. Died in 1845.

Johann Georg Heinrich Hassel, Weimar. Died 18 January, 1829, aged 58.

25 January, 1832.

Sir William Rowan Hamilton, Dublin. Died 2 September, 1865, aged 60.

Charles Lucien Jules Laurence Bonaparte, Prince de Canino. Died 29 July, 1857, aged 54.

Francis Baily, London. Died 30 August, 1844, aged 70.

Sir John Frederick William Herschel, Baronet, Slough. Died 11 May, 1871, aged 79.

Henry Kater, London. Died 26 April, 1835, aged 80.

Charles Babbage, London. Died 20 October, 1871, aged 78.

Peter Barlow, Woolwich. Died 1 March, 1862, aged 85.

Michael Faraday, London. Died 25 August, 1867, aged 75.

Sir George Biddell Airy, Cambridge.

Dominique François Jean Arago, Paris. Died 2 October, 1853, aged 67.

Adrien Marie Legendre, Paris. Died 10 January, 1833, aged 80.

Joseph Louis Gay-Lussac, Paris. Died 9 May, 1850, aged 71.

Friedrich Wilhelm Bessel, Königsberg. Died 17 March, 1846, aged 61.

Barone Giovanni Antonio Amedeo Plana, Turin. Died 20 January, 1864, aged 82.

Sir Everard Home, Baronet, London. Died 31 August, 1832, aged 76.

14 November, 1832.

Davies Gilbert, London. Died 24 December, 1839, aged 72.

Sir John William Lubbock, Baronet, London. Died 20 June, 1865, aged 62.

Augustin Louis, Baron Cauchy, Paris. Died 23 May, 1857, aged 67.

Marie Charles Théodore, Baron de Damoiseau, Paris. Died 6 August, 1846, aged 78.

29 January, 1834.

Heinrich Christian Schumacher, Altona. Died 28 December, 1850, aged 70.

Friedrich Georg Wilhelm Struve, Pulkowa. Died 23 November, 1864, aged 71.

27 May, 1834.

Sir Francis Palgrave, London. Died 6 July, 1861, aged 72.

John Dalton, Manchester. Died 27 July, 1844, aged 77.

Michel Ostrogradsky, St. Petersburg. Died 1 January, 1862, aged 60.

12 November, 1834.

Eduard Albert Christoph Ludwig Collins, St. Petersburg. Died 4 August, 1840, aged 49.

Sir Marc Isambert Brunel, London. Died 12 December, 1849, aged 80.

25 January, 1837.

Niccolò Cacciatore, Palermo. Died 27 January, 1841, aged 61.

Lambert Adolphe Jacques Quetelet, Brussels. Died 17 February, 1874, aged 77.

8 August, 1838.

Domenico Lo Faso Pietra Santa, Duca di Serra di Falco, Palermo. Died 16 February, 1863, aged 79.

13 November, 1839.

Joaquim José da Costa de Macedo, Lisbon. Died 15 March, 1867.

29 January, 1840.

William Vaughan, London. Died 5 May, 1850, aged 97.

19 August, 1840.

Sir Roderick Impey Murchison, Baronet, London. Died 22 October, 1871, aged 79.

11 August, 1841.

Jean Baptiste Benoist Eyriès, Paris. Died 12 June, 1846, aged 78.

10 November, 1841.

Sir Charles Lyell, Baronet, London. Died 22 February, 1875, aged 77.

9 February, 1842.

Marchese Gino Alessandro Giuseppe Gaspardo Capponi, Florence. Died 3 February, 1876, aged 83.

Pascual de Gayangos, Madrid.

30 May, 1843.

Justus Freiherr von Liebig, Giessen. Died 18 April, 1873, aged 69.

13 November, 1844.

Adam Sedgwick, Cambridge, England. Died 27 January, 1873, aged 87.

26 February, 1845.

Stephan Ladislaus Endlicher, Vienna. Died 28 March, 1849, aged 44.

Carl Friedrich Phillip von Martius, Munich. Died 13 December, 1868, aged 74.

26 May, 1846.

Spencer Joshua Alwyne Compton, Marquis of Northampton, London. Died 16 January, 1851, aged 61.

12 August, 1846.

Jean Louis Rodolph Agassiz, Neufchatel. Died 14 December, 1873, aged 66.

Philippe Édouard Poulletier de Verneuil, Paris. Died 29 May, 1873, aged 68.

Joseph Decaisne, Paris.

11 August, 1847.

William Whewell, Cambridge, England. Died 6 March, 1866, aged 71.

Alphonse Louis Pierre Pyramus de Candolle, Geneva.

Urbain Jean Joseph Le Verrier, Paris. Died 23 September, 1877, aged 66.

John Couch Adams, Cambridge, England.

10 November, 1847.

William Henry Smyth, London. Died 9 September, 1865, aged 77.

13 November, 1849.

Johann Franz Encke, Berlin. Died 26 August, 1865, aged 73.

Elias Magnus Fries, Upsal. Died 8 February, 1878, aged 83.

Peter Andreas Hansen, Seeberg. Died 28 March, 1874, aged 78.

Hans Christian Örsted, Copenhagen. Died 9 March, 1851, aged 73.

Heinrich Rose, Berlin. Died 27 January, 1864, aged 68.

Johannes Müller, Berlin. Died 28 April, 1858, aged 56.

Christian Gottfried Ehrenberg, Berlin. Died 27 June, 1876, aged 81.

Carl Ritter, Berlin. Died 28 September, 1859, aged 80.

Christian Leopold, Freiherr von Buch, Berlin. Died 4 March, 1853, aged 78.

Friedrich Tiedemann, Heidelberg. Died 22 January, 1861, aged 79.

Theodor Ludwig Wilhelm Bischoff, Giessen.

Karl Ernst von Baer, St. Petersburg. Died 28 November, 1876, aged 84.

Theodor Schwann, Liége.

Macedonio Melloni, Naples. Died 11 August, 1854, aged 56.

Jean Baptiste André Dumas, Paris.

Henri Milne Edwards, Paris.

Jean Baptiste Armand Louis Léonce Élie de Beaumont, Paris. Died 24 September, 1874, aged 76.

Pierre Charles Alexandre Louis, Paris. Died 9 June, 1872, aged 85.

Gabriel Andral, Paris. Died 13 February, 1876, aged 78.

Benoit Fourneyron, Paris. Died 8 July, 1867, aged 64.

Robert Brown, London. Died 10 June, 1858, aged 84.

Robert Stephenson, London. Died 12 October, 1859, aged 56.

Sir Henry Thomas De la Beche, London. Died 13 April, 1855, aged 59.

28 May, 1850.

Carl Gustav Jacob Jacobi, Berlin. Died 18 February, 1851, aged 46.

Adrien Henri Laurent de Jussieu, Paris. Died 29 June, 1853, aged 55.

Carl Freiherr von Rokitansky, Vienna. Died 23 July, 1878, aged 74.

31 May, 1853.

Christian August Friedrich Peters, Königsberg. Died 8 May, 1880, aged 73.

Karl Joseph Anton Mittermaïer, Heidelberg. Died 28 August, 1867, aged 80.

August Boeckh, Berlin. Died 3 August, 1867, aged 81.

Karl Reichard Lepsius, Berlin.

Christian Carl Josias, Freiherr von Bunsen, Bonn. Died 28 November, 1860, aged 69.

George Grote, London. Died 18 June, 1871, aged 76.

30 May, 1854.

Sir William Hamilton, Edinburgh. Died 6 May, 1856, aged 68.

Carl Theodor Ernst von Siebold, Munich.

14 November, 1855.

Friedrich Wilhelm August Argelander, Bonn. Died 17 February, 1875, aged 75.

Henri Victor Regnault, Paris. Died 19 January, 1878, aged 66.

Louis Joseph Vicat, Grenoble. Died 10 April, 1861, aged 75.

Richard Owen, London.

Sir Benjamin Collins Brodie, Baronet, London. Died 21 October, 1862, aged 79.

Pierre François Olive Rayer, Paris. Died 10 September, 1867, aged 74.

Richard Whately, London. Died 8 October, 1863, aged 76.

Victor Cousin, Paris. Died 14 January, 1867, aged 74.

Franz Bopp, Berlin. Died 23 October, 1867, aged 76.

Friedrich Wilhelm Thiersch, Munich. Died 25 February, 1860, aged 75.

François Pierre Guillaume Guizot, Paris. Died 12 September, 1874, aged 86.

9 December, 1856.

John Stuart Mill, London. Died 8 May, 1873, aged 66.

Manuel John Johnson, Oxford. Died 28 February, 1859, aged 53.

26 May, 1857.

Eilhard Mitscherlich, Berlin. Died 28 August, 1863, aged 69.

Hugo von Mohl, Tubingen. Died 1 April, 1872, aged 66.

Jacob Ludwig Grimm, Berlin. Died 20 September, 1863, aged 78.

26 January, 1859.

John Lindley, London. Died 1 November, 1865, aged 66.

24 May, 1859.

Joseph Liouville, Paris.

9 November, 1859.

Gabriel Gustav Valentin, Berne.

14 November, 1860.

Heinrich Wilhelm Dove, Berlin. Died 4 April, 1879, aged 75.

Rudolf Albert von Kölliker, Wurtzburg.

13 November, 1861.

August Immanuel Bekker, Berlin. Died 6 June, 1871, aged 86.

Friedrich Adolf Trendelenberg, Berlin. Died 24 January, 1872, aged 69.

Louis Isidore Duperrey, Paris. Died 25 August, 1865, aged 78.

29 January, 1862.

Sir William Fairbairn, Baronet, Manchester, England. Died 10 August, 1874, aged 85.

28 January, 1863.

Christopher Hansteen, Christiania. Died 11 April, 1873, aged 88.

Franz Leopold von Ranke, Berlin.

11 November, 1863.

Sir William Lawrence, Baronet, London. Died 5 July, 1867, aged 83.

9 February, 1864.

Henry Hart Milman, London. Died 24 September, 1868, aged 77.

Friedrich Max Müller, Oxford.

Johann Friedrich Overbeck, Rome. Died 12 November, 1869, aged 80.

Thomas Graham, London. Died 16 September, 1869, aged 63.

9 November, 1864.

Michel Chasles, Paris. Died 19 December, 1880, aged 87.

Otto Wilhelm Struve, Pulkowa.

Robert Wilhelm Eberhard Bunsen, Heidelberg.

8 November, 1865.

Jean Victor Poncelet, Paris. Died 27 December, 1867, aged 79.

31 January, 1866.

Arthur Cayley, Cambridge, England.

Charles Eugène Delaunay, Paris. Died 5 August, 1872, aged 56.

Sir Joseph Dalton Hooker, Kew, England.

29 May, 1866.

George Bentham, London.

Hervé Auguste Étienne Albans Faye, Paris.

William John Macquorn Rankine, Glasgow. Died 24 December, 1872, aged 52.

14 November, 1866.

Sir Henry Sumner Maine, London.

28 May, 1867.

Sir Edward Sabine, London.

29 January, 1868.

Auguste Arthur de la Rive, Geneva. Died 27 November, 1873, aged 72.

Michel Eugène Chevreul, Paris.

26 May, 1868.

Johann Caspar Bluntschli, Heidelberg. Died 21 October, 1881, aged 74.

Friedrich Wilhelm Ritschl, Bonn. Died 9 November, 1876, aged 70.

Christian Lassen, Bonn. Died 8 May, 1876, aged 75.

Henry Longueville Mansel, Oxford. Died 31 July, 1871, aged 50.

11 November, 1868.

Sir Charles Wheatstone, London. Died 19 October, 1875, aged 73.

Hermann Ludwig Ferdinand Helmholtz, Heidelberg.

24 May, 1870.

Alexander Carl Heinrich Braun, Berlin. Died 29 March, 1877, aged 71.

Charles Merivale, Ely, England.

9 November, 1870.

Wilhelm Freiherr von Kaulbach, Munich. Died 7 April, 1874, aged 68.

Gustav Robert Kirchhoff, Berlin.

28 May, 1872.

Johann Heinrich Wilhelm Döllen, Pulkowa.

Sir William Thomson, Glasgow.

Theodor Mommsen, Berlin.

James Martineau, London.

Benjamin Jowett, Oxford.

Carl Friedrich Rammelsberg, Berlin.

11 February, 1873.

Wilhelm Friedrich Benedict Hofmeister, Heidelberg. Died 12 January, 1877, aged 52.

27 May, 1873.

Rudolph Julius Emmanuel Clausius, Bonn.

James Joseph Sylvester, Woolwich.

Carl Friedrich Naumann, Munich. Died 26 November, 1873, aged 76.

12 November, 1873.

Charles François Marie, Comte de Rémusat, Paris. Died 6 June, 1875, aged 78.

Friedrich Wöhler, Göttingen.

28 January, 1874.

George Gabriel Stokes, Cambridge, England.

Francesco Brioschi, Milan.

William Ewart Gladstone, London.

Charles Robert Darwin, Beckenham.

26 May, 1874.

James Prescott Joule, Manchester, England.

William Hallowes Miller, Cambridge, England. Died 20 May, 1880, aged 79.

Johann Christian Poggendorff, Berlin. Died 24 January, 1877, aged 80.

11 November, 1874.

James Clerk Maxwell, Cambridge, England. Died 5 November, 1879, aged 48.

Rudolph Virchow, Berlin.

27 January, 1875.

Joachim Barrande, Prague.

Louis Adolphe Thiers, Paris. Died 3 September, 1877, aged 80.

Jean Léon Gérôme, Paris.

10 November, 1875.

Andrew Crombie Ramsay, London.

26 January, 1876.

Count Paolo Federigo Sclopis di Salerano, Turin. Died 8 March, 1878, aged 80.

12 April, 1876.

Balfour Stewart, Manchester.

30 May, 1876.

Alfred Tennyson, Freshwater, Isle of Wight.

François Auguste Alexis Mignet, Paris.

Ernst Curtius, Berlin.

Sir Henry Creswicke Rawlinson, London.

Arthur Penrhyn Stanley, London. Died July 18, 1881, aged 66.

Eugène Emmanuel Viollet-Le-Duc, Paris. Died 17 September, 1879, aged 65.

Mark Pattison, Oxford.

29 May, 1877.

August Wilhelm Hofmann, Berlin.
Oswald Heer, Zurich.
Rudolph Leuckart, Leipsic.
Johann Japetus Smith Steenstrup, Copenhagen.

9 January, 1878.

Carl Nägeli, Munich.

13 March, 1878.

Émile Plantamour, Geneva.

28 May, 1878.

Jacob Georg Agardh, Lund.

9 October, 1878.

Thomas Carlyle, Chelsea, England. Died 5 February, 1881, aged 86.
Hugh Andrew Johnstone Munro, Cambridge, England.
John Ruskin, Coniston, England.

12 March, 1879.

Franz Cornelis Donders, Utrecht.
Ferdinand Marie, Vicomte de Lesseps, Paris.

8 October, 1879.

Sir James Fitzjames Stephen, London.
Georg Curtius, Leipsic.

25 May, 1880.

Marcelin Pierre Eugène Berthelot, Paris.

13 October, 1880.

Arthur Auwers, Berlin.
Alfred Louis Olivier Legrand Des Cloizeaux, Paris.

9 February, 1881.

Charles Édouard Brown-Séquard, Paris.

24 May, 1881.

William Stubbs, Oxford.

ERRATA ET ADDENDA.*

Reuben D. Muzzey died 21 June, 1866, aged 86.
Charles C. Jewett died 9 January, 1868, aged 51.
Joseph G. Cogswell died 26 Nov., 1871, aged 85.
Sylvanus Thayer died 7 Sept., 1872, aged 87.
Johann Caspar Bluntschli died 21 October, 1881, aged 74.
John A. Lowell died 31 October, 1881, aged 82.
John Bacon died 28 November, 1881, aged 64.
Lewis H. Morgan died 17 December, 1881, aged 63.
Edward Reynolds died 25 December, 1881, aged 89.
John W. Draper died 4 January, 1882, aged 71.
Richard H. Dana died 6 January, 1882, aged 67.
Theophilus Parsons died 26 January, 1882, aged 85.
Theodore Schwann died recently.

---

* The residences have generally been given as they were when the members were elected. By moving into Massachusetts, Associate Fellows and Foreign Honorary Members have become Fellows. In some cases of frequent removals, into or out of the State, the rank of the member has fluctuated.

OFFICERS OF THE ACADEMY.

PRESIDENTS.

30 Aug., 1780–1791, James Bowdoin.
24 May, 1791–1814, John Adams.
24 May, 1814–1820, Edward Augustus Holyoke.
30 May, 1820–1829, John Quincy Adams.
26 May, 1829–1838, Nathaniel Bowditch.
29 May, 1838–1839, James Jackson.
28 May, 1839–1846, John Pickering.
26 May, 1846–1863, Jacob Bigelow.
26 May, 1863–1873, Asa Gray.
27 May, 1873–1880, Charles Francis Adams.
9 June, 1880 . . . . Joseph Lovering.

VICE-PRESIDENTS.

30 Aug., 1780–1784, Samuel Cooper.
25 May, 1784–1805, Joseph Willard.
28 May, 1805–1807, Francis Dana.
26 May, 1807–1810, Samuel Webber.
28 May, 1811–1828, John Thornton Kirkland.
27 May, 1828–1829, Nathaniel Bowditch.
26 May, 1829–1831, John Farrar.
24 May, 1831–1839, Josiah Quincy.
28 May, 1839–1846, Jacob Bigelow.
26 May, 1846–1852, Edward Everett.
25 May, 1852–1863, Daniel Treadwell.
26 May, 1863–1866, Charles Beck.
29 May, 1866–1872, George Tyler Bigelow.
28 May, 1872–1873, Charles Francis Adams.
27 May, 1873–1880, Joseph Lovering.
9 June, 1880 . . . . Oliver Wendell Holmes.

CORRESPONDING SECRETARIES.

30 Aug., 1780–1789, Joseph Willard.
26 May, 1789–1802, Eliphalet Pearson.
25 May, 1802–1809, John Quincy Adams.
9 Aug., 1809–1823, Josiah Quincy.
27 May, 1823–1824, John Pickering.
25 May, 1824–1829, Edward Everett.
26 May, 1829–1831, Jacob Bigelow.
24 May, 1831–1837, Francis Calley Gray.
30 May, 1837–1839, John Pickering.
28 May, 1839–1844, Charles Folsom.
27 May, 1844–1850, Asa Gray.
28 May, 1850–1852, Augustus Addison Gould.
25 May, 1852–1863, Asa Gray.
26 May, 1863–1869, William Barton Rogers.
8 June, 1869–1873, Joseph Lovering.
27 May, 1873 . . . . Josiah Parsons Cooke.

RECORDING SECRETARIES.

30 Aug., 1780–1790, Caleb Gannett.
25 May, 1790–1791, Samuel Webber.
24 May, 1791–1795, John Clarke.
19 Aug., 1795–1798, Benjamin Dearborn.
29 May, 1798–1808, John Davis.
24 May, 1808–1811, William Emerson.
28 May, 1811–1823, John Farrar.
27 May, 1823–1825, Edward Everett.
24 May, 1825–1827, James Savage.
29 May, 1827–1829, Francis Calley Gray.
26 May, 1829–1833, Nathan Hale.
28 May, 1833–1839, Daniel Treadwell.
28 May, 1839–1840, Benjamin Peirce.
26 May, 1840–1843, George Barrell Emerson.
30 May, 1843–1845, Francis Bowen.
27 May, 1845–1848, Oliver Wendell Holmes.
30 May, 1848–1850, Augustus Addison Gould.
28 May, 1850–1852, Joseph Hale Abbot.
25 May, 1852–1852, Benjamin Apthorp Gould.
10 Nov., 1852–1854, Samuel Kneeland.
30 May, 1854–1863, Samuel Leonard Abbot.
26 May, 1863–1871, Chauncey Wright.
30 May, 1871–1877, Edward Charles Pickering.
29 May, 1877–1877, Henry Pickering Bowditch.
10 Oct., 1877 . . . . John Trowbridge.

TREASURERS.

30 Aug., 1780–1795, Ebenezer Storer.
27 Jan., 1796–1798, Thomas Welsh.
29 May, 1798–1808, James Freeman.
24 May, 1808–1815, Dudley Atkins Tyng.
30 May, 1815–1834, Thomas Lindall Winthrop.
27 May, 1834–1842, Joseph Tilden.
24 May, 1842–1852, Jonathan Ingersoll Bowditch.
25 May, 1852–1864, Edward Wigglesworth.
20 Sept., 1864–1865, George Livermore.
10 Oct., 1865–1868, John Clarke Lee.
9 June, 1868–1871, Charles James Sprague.
30 May, 1871–1877, Edmund Quincy.
29 May, 1877 . . . . Theodore Lyman.

VICE-TREASURERS.

30 Aug., 1780–1784, Stephen Sewall.
25 May, 1784–1793, Benjamin Guild.
28 May, 1793–1796, Charles Bulfinch.
24 May, 1796–1798, James Freeman.
29 May, 1798–1802, George Richards Minot.
25 May, 1802–1809, William Spooner.
30 May, 1809–1816, John Collins Warren.
28 May, 1816–1829, Jacob Bigelow.
26 May, 1829–1838, Rufus Wyman.

CABINET KEEPERS.

30 Aug., 1780–1782, James Winthrop.
30 Jan., 1782–1783, Stephen Sewall.
27 May, 1783–1791, Caleb Gannett.
24 May, 1791–1805, John Lathrop.
28 May, 1805–1810, Allan Pollock.
29 May, 1810–1823, John Gorham.

LIBRARIANS.

25 May, 1784–1791, Caleb Gannett.
24 May, 1791–1816, John Lathrop.
28 May, 1816–1818, Charles Bulfinch.
26 May, 1818–1823, William Smith Shaw.
25 May, 1830–1832, Willard Phillips.
28 May, 1832–1835, Solomon Pearson Miles.
26 May, 1835–1845, Enoch Hale.
27 May, 1845–1848, Augustus Addison Gould.
30 May, 1848–1849, John Bacon.
29 May, 1849–1852, Henry Ingersoll Bowditch.
25 May, 1852–1858, Nathaniel Bradstreet Shurtleff.
25 May, 1858–1866, Josiah Parsons Cooke.
29 May, 1866–1871, Francis Humphreys Storer.
30 May, 1871–1877, Edmund Quincy.
29 May, 1877 . . . . Samuel Hubbard Scudder.

MEMBERS OF THE COUNCIL.*

30 Aug., 1780–1787, Thomas Cushing.
“ “ 1781, Henry Gardner.
“ “ 1785, John Hancock.
“ “ 1781, Samuel Langdon.
“ “ 1802, John Lowell.
“ “ 1814, Robert Treat Paine.
“ “ 1785, Phillips Payson.
“ “ 1787, James Warren.
“ “ 1782, Edward Wigglesworth.
“ “ 1788, Samuel Williams.
29 May, 1781–1792, Samuel Adams.
28 May, 1782–1784, Joseph Willard.
27 May, 1783–1805, Cotton Tufts.
25 May, 1784–1815, John Warren.
24 May, 1785–1796, Loammi Baldwin.
“ “ 1809, Benjamin Lincoln.
29 May, 1787–1796, Richard Cranch.
“ “ 1790, Edward Wigglesworth.
27 May, 1788–1789, John Adams.
26 May, 1789–1805, Francis Dana.
25 May, 1790–1818, Caleb Gannett.
29 May, 1792–1794, Jeremy Belknap.
27 May, 1794–1798, John Clarke.
24 May, 1796–1816, John Lathrop.
“ “ 1807, Samuel Webber.
29 May, 1798–1807, Loammi Baldwin.
25 May, 1802–1804, Simeon Howard.
28 May, 1805–1806, James Freeman.
“ “ 1809, Eliphalet Pearson.
“ “ 1822, John Davis.
27 May, 1806–1807, Cotton Tufts.
26 May, 1807–1811, Francis Dana.
“ “ 1823, James Freeman.
24 May, 1808–1823, Aaron Dexter.
30 May, 1809–1823, Thomas Dawes.
“ “ 1823, Henry Ware.
28 May, 1811–1823, Charles Bulfinch.
24 May, 1814–1823, William Dandridge Peck.
30 May, 1815–1823, George Cabot.
28 May, 1816–1823, Josiah Quincy.
26 May, 1818–1823, Nathaniel Bowditch.
May, 1821–1823, John Pickering.
25 May, 1852–1854, Benjamin Peirce.
“ “ 1853, William Cranch Bond.
“ “ 1863, Joseph Lovering.
“ “ 1871, Louis Agassiz.
“ “ 1853, Charles Pickering.
“ “ 1863, John Barnard Swett Jackson.
“ “ 1863, James Walker.
“ “ 1853, Cornelius Conway Felton.
“ “ 1858, Nathan Appleton.
31 May, 1853–1858, Benjamin Apthorp Gould, Jr.
“ “ 1854, John Amory Lowell.
“ “ 1856, Jared Sparks.

---

* The original constitution of the Academy provided for the annual election of ten councillors. This provision is not found in the amended constitution, which was printed, in 1833, in the first volume of the second series of Memoirs; and no councillors were elected after 1823. In the new constitution, under which the Academy has been working for more than twenty-five years, the Council was revived, and consists now of the president, vice-president, secretaries, treasurer, and nine other members elected by ballot.

30 May, 1854–1856, Jonathan Ingersoll Bowditch.
" " 1855, George Barrell Emerson.
29 May, 1855–1873, Jeffries Wyman.
27 May, 1856–1863, Eben Norton Horsford.
" " 1858, Francis Bowen.
25 May, 1858–1863, Jonathan Ingersoll Bowditch.
" " 1864, Henry Warren Torrey.
" " 1875, Robert Charles Winthrop.
26 May, 1863–1873, Thomas Hill.
" " 1865, George Phillips Bond.
" " 1877, John Benjamin Henck.
" " 1866, Augustus Addison Gould.
" " 1877, George Edward Ellis.
24 May, 1864–1878, Andrew Preston Peabody.
30 May, 1865–1868, Joseph Lovering.
11 June, 1867–1875, Charles Pickering.
26 May, 1868–1873, Josiah Parsons Cooke.
30 May, 1871–1877, Alexander Agassiz.
27 May, 1873–1875, Benjamin Peirce.
" " 1878, Wolcott Gibbs.
" " 1875, Asa Gray.
25 May, 1875–1877, Charles William Eliot.
" " 1877, John Amory Lowell.
" " 1879, Benjamin Eddy Cotting.
14 Dec., 1875–1876, Robert Charles Winthrop.
30 May, 1876–1877, Charles Callahan Perkins.
29 May, 1877–1878, John Daniel Runkle.
" " 1880, Edward Charles Pickering.
" " 1880, Asa Gray.
" " 1878, Hermann August Hagen.
" " 1877, Samuel Eliot.
" " 1880, Charles Eliot Norton.
28 May, 1878–1881, James Mills Peirce.
" " 1881, John Morse Ordway.
" " 1881, Alexander Agassiz.
" " 1881, Robert Charles Winthrop.
" " 1878, Benjamin Franklin Thomas.
9 Oct., 1878–1879, James Bradley Thayer.
27 May, 1879 . . . . Henry Willard Williams.
8 Oct., 1879–1880, John Chipman Gray, Jr.
9 June, 1880 . . . . Wolcott Gibbs.
" " . . . . George Lincoln Goodale.
" " . . . . Charles Greely Loring.
" " . . . . Francis James Child.
24 May, 1881 . . . . Edward Charles Pickering.
" " . . . . Charles William Eliot.
" " . . . . Henry Pickering Bowditch.
" " . . . . Edward Atkinson.

MEMBERS OF THE RUMFORD COMMITTEES.

30 Jan., 1833–1838, Nathaniel Bowditch.
" " 1837, Francis Calley Gray.
" " 1848, Daniel Treadwell.
" " 1846, Jacob Bigelow.
" " 1849, John Ware.
30 May, 1837–1846, John Pickering.
29 May, 1838–1839, James Jackson.
28 May, 1839–1840, Benjamin Peirce.
26 May, 1840–1843, George Barrell Emerson.
30 May, 1843–1849, Benjamin Peirce.
26 May, 1846–1850, Francis Cabot Lowell.
26 May, 1846–1847, James Hayward.
25 May, 1847–1868, Joseph Lovering.
30 May, 1848–1863, Eben Norton Horsford.
31 Jan., 1849–1863, Daniel Treadwell.
29 May, 1849–1878, Morrill Wyman.
28 May, 1850–1862, Henry Lawrence Eustis.
27 May, 1862–1871, Joseph Winlock.
26 May, 1863–1869, William Barton Rogers.
" " 1864, Charles William Eliot.
" " 1864, Theophilus Parsons.
" " 1866, Cyrus Mores Warren.
24 May, 1864 . . . . Wolcott Gibbs.
14 June, 1864–1871, Francis Humphreys Storer.
29 May, 1866–1877, Josiah Parsons Cooke.
26 May, 1868–1878, James Bicheno Francis.
8 June, 1869 . . . . Edward Charles Pickering.
30 May, 1871 . . . . John Morse Ordway.
30 May, 1871–1880, Stephen Preston Ruggles.
29 May, 1877 . . . . John Trowbridge.
28 May, 1878 . . . . Josiah Parsons Cooke.
28 May, 1878 . . . . Joseph Lovering.
9 June, 1880 . . . . George Bassett Clark.

MEMBERS OF THE COMMITTEES OF PUBLICATION.

1 Apr., 1784–1785, Loammi Baldwin.
" " Ebenezer Storer.
" " Benjamin Guild.
" " Manasseh Cutler.
" " Edward Augustus Holyoke.
19 Aug., 1789–1793, Benjamin Guild.
" " Ebenezer Storer.
" " John Lowell.
21 Aug., 1793–1794, Aaron Dexter.
" " James Freeman.
" " John Clarke.
24 Aug., 1796–1804, Thomas Lyndall Winthrop.
" " James Freeman.
" " Benjamin Dearborn.
" " Jeremy Belknap.
" " John Clarke.
" " John Warren.
" " John Thornton Kirkland.
" " George Richards Minot.
" " Bezaleel Howard.
27 Jan., 1802–1805, John Lathrop.
" " 1805, John Davis.
" " 1805, John Quincy Adams.
" " 1808, James Freeman.
" " 1808, Jedediah Morse.
" " 1805, John Thornton Kirkland.
" " 1810, Samuel Webber.
" " 1805, John Warren.
13 Nov., 1805–1810, John Mellen.
" " 1810, Levi Hedge.
" " 1808, Josiah Quincy.
" " 1808, John Eliot.
" " 1810, Henry Ware.
24 May, 1808–1810, Abiel Holmes.
29 May, 1810–1812, John Davis.
" " 1823, James Freeman.
" " 1823, John Thornton Kirkland.
" " 1828, Nathaniel Bowditch.
" " 1824, John Farrar.
26 May, 1812–1814, Loammi Baldwin.
24 May, 1814–1823, Sidney Willard.
25 May, 1824–1825, John Pickering.
24 May, 1825–1829, Joseph Emerson Worcester.
27 May, 1828–1829, John Farrar.
26 May, 1829–1844, George Hayward.
26 May, 1829–1833, Daniel Treadwell.
28 May, 1833–1844, John Ware.
24 May, 1842–1843, Henry Ingersoll Bowditch.
30 May, 1843–1844, Jonathan Ingersoll Bowditch.
27 May, 1844–1846, George Barrell Emerson.
" " 1847, Amos Binney.
" " 1848, Francis Bowen.
26 May, 1846–1850, Asa Gray.
25 May, 1847–1853, William Cranch Bond.
30 May, 1848–1858, Louis Agassiz.
28 May, 1850–1851, Augustus Addison Gould.
27 May, 1851–1872, Joseph Lovering.
31 May, 1853–1856, Francis Bowen.
27 May, 1856–1862, Cornelius Conway Felton.
25 May, 1858–1873, Jeffries Wyman.
27 May, 1862–1866, Charles Beck.
29 May, 1866–1868, Charles William Eliot.
26 May, 1868–1871, Francis James Child.
30 May, 1871–1880, William Watson Goodwin.
28 May, 1872 . . . . John Trowbridge.
27 May, 1873 . . . . Alexander Agassiz.
9 June, 1880 . . . . Josiah Parsons Cooke.

MEMBERS OF THE COMMITTEES ON THE LIBRARY.

27 May, 1844–1845, Enoch Hale.
" " 1853, David Humphreys Storer.
" " 1849, Benjamin Peirce.
27 May, 1845–1866, Augustus Addison Gould.
29 May, 1849–1850, Uriah Atherton Boyden.
28 May, 1850–1852, Samuel Leonard Abbot.
25 May, 1852–1856, Benjamin Apthorp Gould.
31 May, 1853–1854, Nathaniel Bradstreet Shurtleff.
30 May, 1854–1858, Josiah Parsons Cooke.
27 May, 1856–1858, Jeffries Wyman.
25 May, 1858–1863, William Barton Rogers.
25 May, 1858–1863, George Phillips Bond.

26 May, 1863–1865, William Prescott Dexter.
26 May, 1863–1868, John Benjamin Henck.
30 May, 1865–1871, Charles Pickering.
29 May, 1866–1871, John Bacon.
26 May, 1868–1871, Francis Parkman.
30 May, 1871–1872, Charles Deane.
" " 1872, Francis Humphreys Storer.
" " 1872, Edward Clark Cabot.
28 May, 1872–1873, Henry Gardner Denny.
" " 1873, John Daniel Runkle.
" " 1873, Jules Marcou.
27 May, 1873–1877, Charles Deane.
" " 1874, William Watson.
" " . . . . Henry Pickering Bowditch.
26 May, 1874 . . . . William Ripley Nichols.
29 May, 1877 . . . . Edward Charles Pickering.

OFFICERS OF THE ACADEMY.

1881-82.

Joseph Lovering, *President.*
Oliver W. Holmes, *Vice-President.*
Josiah P. Cooke, *Corresponding Secretary.*
John Trowbridge, *Recording Secretary.*
Theodore Lyman, *Treasurer.*
Samuel H. Scudder, *Librarian.*

COUNCIL.

Class I.	*Class II.*	*Class III.*
Charles W. Eliot,	Henry P. Bowditch,	Edward Atkinson,
Wolcott Gibbs,	George L. Goodale,	Francis J. Child,
Edward C. Pickering.	Henry W. Williams.	Charles G. Loring.

RUMFORD COMMITTEE.

Josiah P. Cooke,
George B. Clark,
Wolcott Gibbs,
Joseph Lovering,
John M. Ordway,
Edward C. Pickering,
John Trowbridge.

COMMITTEE ON PUBLICATIONS.

Alexander Agassiz,
William W. Goodwin,
John Trowbridge.

COMMITTEE ON LIBRARY.

Henry P. Bowditch,
William R. Nichols,
Edward C. Pickering.

COMMITTEE ON FINANCE.

Ex Officio.	*By Election.*
Joseph Lovering,	Thomas T. Bouvé.
Theodore Lyman.	

AUDITING COMMITTEE.

Henry G. Denny,
Robert W. Hooper.

INDEX TO NAMES OF FELLOWS.

CHARTER OF INCORPORATION:

Granted May 4, 1780, *by an Act of the Legislature of Massachusetts, entitled: An Act to incorporate and establish a Society for the cultivation and promotion of Arts and Sciences.*

As the Arts and Sciences are the foundation and support of agriculture, manufactures, and commerce; as they are necessary to the wealth, peace, independence, and happiness of a people; as they essentially promote the honor and dignity of the government which patronizes them; and as they are most effectually cultivated and diffused through a State by the forming and incorporating of men of genius and learning into public societies: For these beneficent purposes,

Be it therefore enacted by the Council and House of Representatives in General Court assembled, and by the authority of the same: That[1]

be, and they are hereby formed into, constituted, and made a Body Politic and Corporate, by the name of THE AMERICAN ACADEMY OF ARTS AND SCIENCES; and that they and their successors, and such other persons as shall be elected in the manner hereafter mentioned, shall be and continue a Body Politic and Corporate, by the same name forever.

And be it further enacted by the authority aforesaid: That the Fellows of the said Academy may from time to time elect a President, one or more Vice-Presidents, one or more Secretaries, and such other officers of the said Academy as they shall judge necessary or convenient; and they shall have full power and authority from time to time to determine and establish the names, number, and duties of their several officers, and the tenure or estate they shall respectively have in their offices; and also to authorize and empower their President, or some other Fellow of the Academy, at their pleasure, to administer such oaths to such officers as they shall appoint and determine, for the well-ordering and good government of the said Academy: provided the same be not repugnant to the laws of the State.

And be it further enacted by the authority aforesaid: That the Fellows of the said Academy shall have one Common Seal, which they may make use of in whatsoever cause or business shall concern the Academy, or be relative to the end and design of its institution; and shall have power and authority from time to time to break, change, and renew the Common Seal, at their pleasure; and

---

[1] For the names of the Fellows incorporated, see pp. 33, 34.

that they may sue and be sued in all actions, real, personal, and mixed, and prosecute and defend the same unto final judgment and execution, by the name of the President and Fellows of the *American* Academy of Arts and Sciences.

And be it further enacted by the authority aforesaid: That the Fellows of the said Academy may from time to time elect such persons to be Fellows thereof as they shall judge proper; and that they shall have full power and authority from time to time to suspend, expel, or disfranchise any Fellow of the said Academy who shall by his conduct render himself unworthy of a place in that body, in the judgment of the Academy; and also to settle and establish the rules, forms, and conditions of election, suspension, expulsion, and disfranchisement. *Provided,* That the number of the said Academy who are inhabitants of this State shall not, at any one time, be more than two hundred, nor less than forty.

And be it further enacted by the authority aforesaid: That the Fellows of the said Academy shall have full power and authority from time to time to make and enact such reasonable rules, orders, and by-laws, not repugnant to the laws of this State, as shall be necessary or convenient for the well-ordering and good government of the said Academy; and to annex reasonable pecuniary fines and penalties to the breach of them, not exceeding the sum of *twenty pounds,* to be sued for and recovered in any court of record within this State, in the name and for the use of the President and Fellows of the said Academy; and the same rules, orders, and by-laws to repeal at their pleasure; and also to settle and establish the times, places, and manner of convening the Fellows of the said Academy; and also to determine the number of Fellows which shall be present to constitute a meeting of the said Academy. *Provided,* That the Fellows of the said Academy shall meet twice in a year at the least; and that the place of their meeting shall never be more than thirty miles distant from the town of *Boston.*

And be it further enacted by the authority aforesaid: That the Fellows of the said Academy may, and shall forever hereafter be deemed capable in the law of having, holding, and taking in fee-simple or any less estate, by gift, grant, devise, or otherwise, any lands, tenements, or other estate, real and personal. *Provided,* That the annual income of the said real estate shall not exceed the sum of *five hundred pounds,* and the annual income or interest of the said personal estate shall not exceed the sum of *two thousand pounds.* All the sums aforementioned in this act to be valued in silver, at the rate of *six shillings and sixpence* by the ounce. And the annual interest and income of the said real and personal estate, together with the fines and penalties aforesaid, shall be appropriated for premiums to encourage improvements and discoveries in agriculture, arts, and manufactures, or for other purposes consistent with the end and design of the institution of the said Academy, as the Fellows thereof shall determine.

And be it further enacted by the authority aforesaid: That the end and design of the institution of the said Academy is, to promote and encourage the knowledge of the antiquities of *America,* and of the natural history of the country, and to determine the uses to which the various natural productions of the country may be applied; to promote and encourage medical discoveries, mathematical disquisitions, philosophical inquiries and experiments; astronomical, meteorological, and geographical observations, and improvements in agriculture, arts, manufactures, and commerce; and, in fine, to cultivate every art and science which may tend to advance the interest, honor, dignity, and happiness of a free, independent, and virtuous people.

And it is further enacted: That the place where the first meeting of the Fellows of the said Academy shall be held, shall be the Philosophy Chamber in the University of *Cambridge;* and that the Honorable *James Bowdoin,* Esq. be, and he hereby is authorized and empowered to fix the time for holding the said meeting, and to notify the same to the Fellows of the Academy.

STATUTES

OF THE

AMERICAN ACADEMY OF ARTS AND SCIENCES.

(Adopted immediately after the Act of Incorporation.)

CHAPTER I.

OF OFFICERS AND THE MANNER OF THEIR ELECTION.

1. THERE shall be a President, one Vice-President, ten Counsellors, two Secretaries, a Treasurer, a Vice-Treasurer, and a Keeper of the Cabinet: which officers shall be annually elected by written votes on the day next preceding the last Wednesday in May.

2. In order to this election, the President, or in his absence the Vice-President, or in the absence of the President and Vice-President, the senior Counsellor present shall take the chair, at three o'clock, P. M., and after the choice of three scrutineers by nomination, the ballot shall begin and remain open till five o'clock, at which time it shall be closed; upon which, should it appear in any instance that there is no choice, the balloting shall be renewed till a choice is made.

3. Each Elector shall deliver his balloting list, folded, to the President, and a scrutineer, sitting by the President with a list of the Members of the Academy present before him, shall mark the name of each person so delivering in his list.

4. When the ballot is closed, the scrutineer shall sort the votes, and report the same to the chair; after which, the presiding member shall declare the persons, who have the majority of votes, to be the officers respectively for the ensuing year.

5. If either of the Secretaries, the Treasurer, or the Keeper of the Cabinet die, resign, or be removed during the year, at the next meeting of the Academy the vacant office or offices shall be filled by written votes for the remaining part of the year.

6. At all elections of officers, if the suffrages should be equal, the decision shall be by lots prepared by the scrutineers, and drawn by the President.

7. Notwithstanding the election of officers be annual, the Academy reserve to themselves a power of removing any of them for neglect of their trust, or disobedience to the orders of the Academy.

8. A Messenger may be appointed or removed at any meeting of the Academy.

CHAPTER II.

OF THE PRESIDENT AND VICE-PRESIDENT.

1. THE business of the President, or in his absence of the Vice-President, or in the absence of the President and Vice-President, then of the senior Counsellor present, shall be to preside in the meetings, and to regulate the debates of the Academy and Council; to state and put questions both in the affirmative and negative, according to motions regularly made; to call for reports and accounts from Committees and others; to preserve decorum; to summon all meetings of the Council, and all extraordinary meetings of the Academy, by advice of Council, upon any urgent occasions; and to execute or to see to the execution of the statutes of the Academy.

2. The President, or in his absence the Vice-President or presiding Counsellor, is empowered to draw upon the Treasurer for such sums of money as the Academy shall direct.

CHAPTER III.

OF THE COUNCIL.

1. THE Council shall have full authority, and it is their incumbent duty, from time to time, to originate such laws, statutes, orders and constitutions, as shall appear to them to be necessary or useful, according to their judgment and discretion, for the regulation, government, and promotion of the design of the Academy: all which laws, statutes, orders, and constitutions, shall be by them presented at a meeting of the Academy for the approbation of the Fellows; also to prepare such other matters as they may judge proper to be pursued by the Academy, in order to advance in the best manner the end of its institution. Nevertheless, no Fellow is hereby precluded from laying before the Academy such matters, or proposing such laws, as he shall think conducive to its benefit.

2. The Council, with the President and Treasurer, have power to make conclusive bargains for real or personal estate, for the benefit of the Academy, and to rent the same, and to give orders

concerning the improvement of the estate, goods, lands and revenues of the Academy, pursuant to the orders of the Academy.

3. Every deed or writing to which the Common Seal is to be affixed, shall be passed and sealed in Council, and signed by the President, and four, at the least, of the Council.

4. During the recesses of the Academy, the Council shall direct the Secretaries in such correspondence as they shall find expedient. The whole of which shall be laid before the Academy at its next meeting.

5. The Council shall order such papers and letters to be recorded as they shall think proper.

CHAPTER IV.

Of the Secretaries.

1. One of the Secretaries shall have the charge and custody of the Charter and Statute-Book, Journal-Books, Register-Books, and all literary papers belonging to the Academy; and also all letters, after they have been recorded, shall be kept by him on file. This Secretary, if possible, shall attend at all meetings of the Academy and Council, where, when the presiding member hath taken the chair, he shall read the orders and entries of the last precedent meeting, and shall take notes of the orders and transactions of the present meeting, to be entered by him in the respective books to which they relate. And when there shall be a competent number for making elections, he shall give notice of any candidates that shall stand propounded in order to election into the Academy.

2. The other Secretary shall have the charge and custody of the letter-books belonging to the Academy. He shall attend all meetings of the Academy and Council, and read all letters sent to the Academy, or to any member in his academical capacity, and draw up all letters to be written to any persons in the name of the Academy or Council (to be read and approved of in some meeting of either, respectively) except, for some particular cause and consideration, some other person or persons be appointed by the Academy or Council, to draught any such letter. He shall also enter all letters that shall be directed by the Academy or the Council, and when entered, the originals shall be delivered to the first-mentioned Secretary in order to their being filed.

3. At every meeting of the Academy, the Secretary, in whose custody the letter-books are, shall read any entries that the presiding member shall direct; and the Secretary, in whose custody the originals are, shall have with him, ready to produce, the file of all letters received since the last precedent meeting, that, if it be required, a comparison may be made.

4. Each Secretary shall deliver an attested copy of any transaction of the Academy, or paper belonging to his particular department, to any member, upon his producing a written licence from

the Council for that purpose; and to any other person, who shall produce a licence from the Academy signed by the presiding member, and in no other case whatever.

5. Whenever any copy shall be delivered by a Secretary, the person, upon receiving it, shall pay him such fees as the Academy may establish.

CHAPTER V.

Of the Treasurer and Vice-Treasurer.

1. The Treasurer and Vice-Treasurer shall give such security as the Academy shall require for the trust reposed in them respectively.

2. The Treasurer shall receive officially all monies or sums of money due or payable, and all bequests and donations that may be made to the Academy: and by order of the President or presiding member, shall pay such sums as the Academy or the Council shall direct, pursuant to the orders of the Academy, and shall make no disbursements of money otherwise, and shall keep a particular account of such orders, receipts, and payments.

3. All monies or sums of money whereof there shall not be present occasion for expending, or disposing to the use of the Academy, shall be put out to interest on such securities, or otherwise disposed of as the Academy, or the President and Council, pursuant to the orders of the Academy, shall direct.

4. The Treasurer's accounts shall be annually audited by a Committee appointed by the Academy for that purpose, in which appointment not more than one member of the Council shall be included.

5. In case of the death, resignation or removal of the Treasurer, the Vice-Treasurer is empowered to receive all books, papers, and effects, that were in the custody of the Treasurer, and which belong to the Academy, and to give receipts and discharges for the same in the name of the Academy. A duplicate of which signed by the Vice-Treasurer shall be filed with the President. The same process shall be observed upon the choice of a new Treasurer, and his acceptance of the office.

CHAPTER VI.

Of the Keeper of the Cabinet.

1. The Keeper of the Cabinet shall receive and have in his charge and custody, all productions of nature and works of art, that shall be purchased by, or presented to the Academy. He shall

arrange them according to their respective classes in natural history, philosophy, &c., at his own discretion; unless he be directed therein by a Committee of the Academy for that purpose. He shall also, in a book to be kept by him, register the various articles in classes corresponding to the arrangement of the articles themselves, with the description that may accompany the article, the donor's name, and the place whence taken; and the time when presented.

2. He shall attend the exhibitions of the articles in his custody, whenever the Academy shall meet; and no person shall be admitted to a view of them at any other time, unless in presence of the Keeper of the Cabinet, or some member appointed by the Council for that purpose.

3. He shall be Librarian to the Academy 'till they shall judge it expedient to appoint a distinct person to that office.

4. He shall give such security as the Academy shall judge proper for the faithful discharge of his office, and for surrendering the articles in his custody, whenever required by the Academy.

CHAPTER VII.

OF THE MEETINGS OF THE ACADEMY AND COUNCIL.

1. THERE shall annually be four stated meetings of the Academy, viz., On the last Wednesday in *January*, and the day next preceding the last Wednesday in *May*, at *Boston*, and on the Wednesday next preceding the last Tuesday in *August*, and the second Wednesday in *November* at the University in *Cambridge*. Provided that in case the President shall at either of the said annual meetings, within the year of his first appointment, think proper to deliver, before the Academy, an inaugural oration or philosophical discourse, the place of such meeting may be at *Boston* or *Cambridge*, according as it shall be most convenient to him: of which he shall give notice at some preceding meeting of the Academy. — The Council shall also meet four times annually, viz., On the first Wednesday in *January*, and the first Wednesday in *May*, at *Boston;* and on the first Wednesday in *August*, and the third Wednesday in *October*, at *Cambridge:* unless it should by any means be unsafe for the Academy or Council to convene at either of the places above-mentioned, at the times specified. In which case the President, with the advice of the Council, may appoint the next stated meeting of the Academy, at any place within thirty miles distance from *Boston;* and the President in the above-mentioned case may appoint a meeting of the Council within the above said limits.

2. Extraordinary meetings of the Academy may be called at any time or place within thirty miles distance from *Boston*, by the President with the advice of the Council. And extraordinary meetings of the Council may be called by the President within the aforesaid limits, whenever he shall judge it necessary.

3. Eleven Fellows shall be present to constitute a meeting of the Academy, unless for the purposes of receiving communications, and adjourning, in which cases, seven shall be a quorum. And at any meeting of the Council the presiding member, with four others of the Council, are required to be present, in order to transact any business proper to the Council.

4. At all meetings of the Academy or Council the President, and Vice-President, or in their absence, the presiding member shall have a right to vote in common with the other members of either body respectively.

5. No person shall be introduced to any meeting of the Academy but by vote of the Academy, except *American* and foreign Ambassadors, members of Congress, members of the Supreme Legislative and Executive of the State of *Massachusetts* for the time being, and members of similar institutions with this Academy, who may be introduced by any member of the Academy.

6. All meetings of the Academy shall be advertised in two at least of the public news-papers, fourteen days previous to such meeting, by one of the Secretaries under direction of the President, or in his absence of the Vice-President, or presiding member of the Council.

7. All meetings of the Council shall be notified to the several members by billets from the President, or one of the Secretaries under direction of the President, or in his absence, of the Vice-President or presiding member of the Council, seven days, at least, before the time stated or proposed for a meeting.

CHAPTER VIII.

OF FELLOWS.

1. No person shall be elected a Fellow of the Academy, unless proposed and recommended by one or more of the members, nor nominated to the Academy until he has first been proposed to the Council, and they have consented to such nomination; and the name, place of abode, and addition of the person recommended, shall be delivered in, signed by the proposers, and read by one of the Secretaries. A fair copy of such paper, with the date when delivered, shall be hung up in the room, where the Academy shall from time to time meet, on which the Candidates may be balloted for at the next, or some succeeding meeting. And if three-fourths of the Fellows then present shall ballot in his favor, he shall be a member.

2. Each Fellow residing in the State of *Massachusetts*, shall be subject to an annual payment of *Spanish* milled dollars in specie, or an equivalent in bills of the current exchange. Fellows without the State shall be subject to no other annual payment, than they voluntarily consent to.

CHAPTER IX.

OF PROCEEDINGS ON LITERARY PERFORMANCES.

1. THE Academy will never give their judgment, or opinion, upon any literary performance presented to them, but allow it to rest upon its own merit, and the credit of its author.

CHAPTER X.

OF OATHS.

1. THE President, Vice-President, Counsellors, Secretaries, Treasurer, Vice-Treasurer, and Keeper of the Cabinet, shall each take the following oath, *mutatis mutandis:*

I A. B. *elected to the office of* *in the* American Academy of Arts and Sciences, *do swear, that I will, according to my best judgment and discretion, faithfully discharge the duties of the trust reposed in me.*

So help me GOD.

STATUTES

OF THE

AMERICAN ACADEMY OF ARTS AND SCIENCES.

(*Adopted about* 1823.)

CHAPTER I.

Of Officers.

1. There shall be a President, a Vice-President, a Corresponding Secretary, a Recording Secretary, a Treasurer, a Vice-Treasurer, and a Librarian or Keeper of the Library, which officers shall be annually elected by written votes, the day next preceding the last Wednesday in May.

2. If either of the Secretaries, the Treasurer, or the Keeper of the Library die, resign, or be removed during the year, the vacant office or offices shall, at the next meeting of the Academy, be filled by written votes for the remainder of the year.

CHAPTER II.

Of the President.

1. It shall be the duty of the President, and, in his absence, of the Vice-President or next officer in order, as above enumerated, to preside at the meetings of the Academy; to summon extraordinary meetings of the Academy, upon any urgent occasion; and to execute or see to the execution of the statutes of the Academy.

2. The President, or, in his absence, the next officer in order as above enumerated, is empowered to draw upon the Treasurer for such sums of money as the Academy shall direct.

3. Any deed or writing, to which the Common Seal is to be affixed, shall be signed and sealed by the President, when thereto authorized by the Academy.

CHAPTER III.

Of the Secretaries.

1. The Corresponding Secretary shall keep the letter-book, shall record all letters addressed to the Academy, and deliver the originals to be filed to the Recording Secretary: and at each meeting the Corresponding Secretary shall read such letters as have been addressed to the Academy since the last meeting.

2. The Recording Secretary shall have charge of the Charter and statute-book, journals, and all literary papers belonging to the Academy; and all letters, after they have been recorded, shall be kept by him on file. He shall keep a record of the proceedings of the Academy at its meetings; and after each meeting is duly opened by the presiding officer, the proceedings of the last meeting shall be read by the Recording Secretary.

3. Until the further order of the Academy, it shall be the duty of the Corresponding Secretary to transmit to every Fellow thereof, residing in foreign countries, one copy of each volume of Memoirs hereafter published, as soon as convenient.

4. Any Fellow of the Academy residing without the limits of Massachusetts shall be entitled to receive one copy of each volume hereafter published, by applying personally, or by written order, for the same within two years after such publication.

CHAPTER IV.

Of the Treasurer and Vice-Treasurer.

1. The Treasurer and Vice-Treasurer shall give such security, as the Academy may require, for the trust reposed in them severally.

2. The Treasurer shall receive officially all moneys or sums of money, due or payable, and all bequests or donations made, to the Academy; and, by order of the President or presiding officer, shall pay such sums as the Academy shall direct: and shall keep an account of all receipts and expenditures.

3. All moneys or sums of money which there shall not be present occasion to expend, shall be put out at interest on such securities, or otherwise disposed of, as the Academy shall direct.

4. The Treasurer shall keep a separate account of the income and appropriation of the Rumford Fund, and report the same annually.

5. The Treasurer's accounts shall be annually audited by a committee appointed by the Academy for the purpose.

6. In case of the death, resignation, or removal of the Treasurer, the Vice-Treasurer shall discharge his duties.

CHAPTER V.

LIBRARY AND CABINET.

1. It shall be the duty of the Librarian, or the Keeper of the Library, to take charge of the books, to keep a correct catalogue of the same, and to deliver books to the Fellows of the Academy.

2. Any Fellow of the Academy may have at any one time three volumes from the Library.

3. Books may be kept out three calendar months, and no longer; and every person shall be subjected to a fine of twenty cents a week, for every volume retained beyond that time.

4. Every person, who takes a book from the Library, shall give a receipt for the same to the Librarian or his Assistant.

5. Every book shall be returned in good order, regard being had to the necessary wear of the book with good usage. And if any book shall be lost or injured, the person, to whom it stands charged, shall replace it by a new volume or set, if it belong to a set, or pay the current price of the volume or set to the Librarian; and thereupon, the remainder of the set, if the volume belonged to a set, shall be delivered to the person so paying for the same.

6. All books shall be returned to the Library for examination, at least one week before the annual meeting. And every person then having one or more books and neglecting to return the same, as herein required, shall forfeit and pay a fine of one dollar.

7. At the meeting of the Academy in May, a committee shall be chosen to examine the Library, and make report of its condition at the next annual meeting.

CHAPTER VI.

OF MEETINGS.

1. THERE shall be annually four stated meetings of the Academy: namely, on the last Wednesday in January, the day next preceding the last Wednesday in May, the second Wednesday in August, and the second Wednesday in November, to be held at the Hall of the Academy, in Boston.

2. The President shall have power to call extraordinary meetings of the Academy, at such time and place as he shall see fit.

3. Seven Fellows shall constitute a quorum for the transaction of business of every description, which may come before the Academy.

4. The meetings of the Academy shall be advertised in the public papers, by the Recording Secretary.

CHAPTER VII.

Of Fellows.

1. No person shall be elected a Fellow of the Academy, unless proposed and recommended by one or more Fellows, who shall subscribe their names to the recommendation upon the nomination-list. The name shall stand on the nomination-list at least during the interval between two statute meetings, previous to the election. Three fourths of the votes given shall be necessary to constitute a majority for the admission of a member; and when three fourths shall amount to less than seven, then seven votes shall be necessary. Should any person, on balloting, not be admitted, his name shall be removed from the nomination-list: but may at any future period be placed upon it again for a new nomination.

2. Each Fellow residing in the State of Massachusetts shall pay annually two dollars to the Academy.

CHAPTER VIII.

On Literary Performances.

1. The Academy will never express its judgment on literary performances or memoirs submitted to it.

2. The President, Vice-President, and Secretaries, with such others as the Academy may see fit to join, shall constitute a Committee of Publications, to which Committee all memoirs submitted to the Academy, shall be referred.

RUMFORD PREMIUM.

In conformity with the last will of Benjamin Count Rumford, granting a certain fund to the American Academy of Arts and Sciences, and of a decree of the Supreme Judicial Court for carrying into effect the general charitable intent and purpose of Count Rumford, as expressed in his said will, the Academy is empowered to make from the income of said fund, as it now exists, at any annual meeting, an award of a gold and silver medal, being together of the intrinsic value of three hundred dollars, as a premium, to the author of any important discovery or useful improvement on light or on heat, which shall have been made and published by printing, or in any way made known to the public, in any part of the Continent of America, or any of the American Islands; preference being always given to such discoveries as shall, in the opinion of the Academy, tend most to promote the good of mankind; and to add to such medals, as a further premium for such discovery and improvement, if the Academy see fit so to do, a sum of money not exceeding three hundred dollars.

For this purpose a standing Committee is appointed annually by the Academy in May, to consider and report on all applications for the Rumford Premium.

STATUTES

AND

STANDING VOTES

OF THE

AMERICAN ACADEMY OF ARTS AND SCIENCES.

(*Adopted May* 30, 1854: *amended September* 8, 1857, *November* 12, 1862, *May* 24, 1864, *November* 9, 1870, *February* 11, 1873, *and January* 26, 1876.)

CHAPTER I.

OF FELLOWS AND FOREIGN HONORARY MEMBERS.

1. THE Academy consists of *Fellows* and *Foreign Honorary Members.* They are arranged in three classes, according to the Arts and Sciences in which they are severally proficient, viz.: Class I. The Mathematical and Physical Sciences; Class II. The Natural and Physiological Sciences; Class III. The Moral and Political Sciences. Each Class is divided into four Sections, viz.: Class I. Section 1. Mathematics; Section 2. Practical Astronomy and Geodesy; Section 3. Physics and Chemistry; Section 4. Technology and Engineering. Class II. Section 1. Geology, Mineralogy, and Physics of the Globe; Section 2. Botany; Section 3. Zoölogy and Physiology; Section 4. Medicine and Surgery. Class III. Section 1. Philosophy and Jurisprudence; Section 2. Philology and Archæology; Section 3. Political Economy and History; Section 4. Literature and the Fine Arts.

2. Fellows resident in the State of Massachusetts can alone vote at the meetings of the Academy.[1] They shall each pay to the Treasurer the sum of ten dollars on admission, and an annual assessment of ten dollars, with such additional sum, not exceeding five dollars, as the Academy shall, by a standing vote, from time to time determine.

3. Fellows residing out of the State of Massachusetts shall be known and distinguished as Associate Fellows. They shall not be liable to the payment of any fees or annual dues, but, on

---

[1] The number of Resident Fellows is limited by the Charter to 200.

removing within the State, shall be admitted to the privileges,[1] and be subject to the obligations, of Resident Fellows. The number of Associate Fellows shall not exceed *one hundred*, of whom there shall not be more than *forty* in either of the three classes of the Academy.

4. The number of Foreign Honorary Members shall not exceed *seventy-five;* and they shall be chosen from among persons most eminent in foreign countries for their discoveries and attainments in either of the three departments of knowledge above enumerated. And there shall not be more than thirty Foreign Members in either of these departments.

CHAPTER II.

Of Officers.

1. There shall be a President, a Vice-President, a Corresponding Secretary, a Recording Secretary, a Treasurer, and a Librarian, which officers shall be annually elected, by written votes at the Annual Meeting, on the day next preceding the last Wednesday in May.

2. At the same time and in the same manner, nine Councillors shall be elected, three from each Class of the Academy, but the same Fellows shall not be eligible on more than three successive years. These nine Councillors, with the President, Vice-President, the Treasurer, and the two Secretaries, shall constitute the Council. It shall be the duty of this Council to exercise a discreet supervision over all nominations and elections. With the consent of the Fellow interested, they shall have power to make transfers between the several sections of the same Class, reporting their action to the Academy.

3. If any office shall become vacant during the year, the vacancy shall be filled by a new election, and at the next stated meeting.

CHAPTER III.

Of the President.

1. It shall be the duty of the President, and, in his absence, of the Vice-President or next officer in order, as above enumerated, to preside at the meetings of the Academy; to summon extraordinary meetings, upon any urgent occasion; and to execute or see to the execution of the Statutes of the Academy.

---

[1] Associate Fellows may attend but cannot vote at meetings of the Academy. See Chapter I. 2.

2. The President, or, in his absence, the next officer as above enumerated, is empowered to draw upon the Treasurer for such sums of money as the Academy shall direct. Bills presented on account of the Library, or the publications of the Academy, must be previously approved by the respective committees on these departments.

3. The President, or, in his absence, the next officer as above enumerated, shall nominate members to serve on the different committees of the Academy which are not chosen by ballot.

4. Any deed or writing, to which the common seal is to be affixed, shall be signed and sealed by the President, when thereto authorized by the Academy.

CHAPTER IV.

OF STANDING COMMITTEES.

1. AT the Annual Meeting there shall be chosen the following Standing Committees, to serve for the year ensuing, viz.: —

2. The Committee of Finance, to consist of the President, Treasurer, and one Fellow chosen by ballot, who shall have charge of the investment and management of the funds and trusts of the Academy. The general appropriations for the expenditures of the Academy shall be moved by this Committee at the Annual Meeting, and all special appropriations from the general and publication funds shall be referred to or proposed by this Committee.

3. The Rumford Committee, of seven Fellows, to be chosen by ballot, who shall consider and report on all applications and claims for the Rumford Premium, also on all appropriations from the income of the Rumford Fund, and generally see to the due and proper execution of this trust.

4. The Committee of Publication, of three Fellows, to whom all Memoirs submitted to the Academy shall be referred, and to whom the printing of Memoirs accepted for publication shall be intrusted.

5. The Committee on the Library, of three Fellows, who shall examine the Library, and make an annual report on its condition and management.

6. An Auditing Committee, of two Fellows, for auditing the accounts of the Treasurer.

CHAPTER V.

Of the Secretaries.

1. The Corresponding Secretary shall conduct the correspondence of the Academy, recording or making an entry of all letters written in its name, and preserving on file all letters which are received; and at each meeting he shall present the letters which have been addressed to the Academy since the last meeting. With the advice and consent of the President, he may effect exchanges with other scientific associations, and also distribute copies of the publications of the Academy among the Associate Fellows and Foreign Honorary Members, as shall be deemed expedient; making a report of his proceedings at the Annual Meeting. Under the direction of the Council for Nomination, he shall keep a list of the Fellows, Associate Fellows, and Foreign Honorary Members, arranged in their Classes and in Sections in respect to the special sciences in which they are severally proficient; and he shall act as secretary to the Council.

2. The Recording Secretary shall have charge of the Charter and Statute-book, journals, and all literary papers belonging to the Academy. He shall record the proceedings of the Academy at its meetings; and, after each meeting is duly opened, he shall read the record of the preceding meeting. He shall notify the meetings of the Academy, and apprise committees of their appointment. He shall post up in the Hall a list of the persons nominated for election into the Academy; and, when any individual is chosen, he shall insert in the record the names of the Fellows by whom he was nominated.

3. The two Secretaries, with the Chairman of the Committee of Publication, shall have authority to publish such of the proceedings of the Academy as may seem to them calculated to promote the interests of science.

CHAPTER VI.

Of the Treasurer.

1. The Treasurer shall give such security for the trust reposed in him as the Academy shall require.

2. He shall receive officially all moneys due or payable, and all bequests or donations made to the Academy, and by order of the President or presiding officer shall pay such sums as the Academy may direct. He shall keep an account of all receipts and expenditures; shall submit his accounts to the Auditing Committee; and shall report the same at the expiration of his term of office.

3. The Treasurer shall keep a separate account of the income and appropriation of the Rumford Fund, and report the same annually.

4. All moneys which there shall not be present occasion to expend shall be invested by the Treasurer, under the direction of the Finance Committee, on such securities as the Academy shall direct.

CHAPTER VII.

OF THE LIBRARIAN AND LIBRARY.

1. IT shall be the duty of the Librarian to take charge of the books, to keep a correct catalogue of the same, and to provide for the delivery of books from the Library. He shall also have the custody of the publications of the Academy.

2. The Librarian, in conjunction with the Committee on the Library, shall have authority to expend, as they may deem expedient, such sums as may be appropriated, either from the Rumford or the General Fund of the Academy, for the purchase of books and for defraying other necessary expenses connected with the Library. They shall have authority to propose rules and regulations concerning the circulation, return, and safe-keeping of books; and to appoint such agents for these purposes as they may think necessary.

3. To all books in the Library procured from the income of the Rumford Fund, the Librarian shall cause a stamp or label to be affixed, expressing the fact that they were so procured.

4. Every person who takes a book from the Library shall give a receipt for the same to the Librarian or his assistant.

5. Every book shall be returned in good order, regard being had to the necessary wear of the book with good usage. And if any book shall be lost or injured, the person to whom it stands charged shall replace it by a new volume or set, if it belong to a set, or pay the current price of the volume or set to the Librarian; and thereupon the remainder of the set, if the volume belonged to a set, shall be delivered to the person so paying for the same.

6. All books shall be returned to the Library for examination, at least one week before the Annual Meeting.

CHAPTER VIII.

Of Meetings.

1. There shall be annually four stated meetings of the Academy; namely, on the day next preceding the last Wednesday in May (the Annual Meeting), on the second Wednesday in October, on the second Wednesday in January, and on the second Wednesday in March; to be held in the Hall of the Academy, in Boston. At these meetings only, or at meetings adjourned from these and regularly notified, shall appropriations of money be made, or alterations of the statutes or standing votes of the Academy be effected.

2. Fifteen Fellows shall constitute a quorum for the transaction of business at a stated meeting. Seven Fellows shall be sufficient to constitute a meeting for scientific communications and discussions.

3. The Recording Secretary shall notify the meetings of the Academy to each Fellow residing in Boston and the vicinity; and he may cause the meetings to be advertised, whenever he deems such further notice to be needful.

CHAPTER IX.

Of the Election of Fellows and Honorary Members.

1. Elections shall be made by ballot, and only at stated meetings.

2. Candidates for election as Resident Fellows must be proposed by two or more Resident Fellows in a recommendation signed by them specifying the section to which the nomination is made, which recommendation shall be transmitted to the Corresponding Secretary, and by him referred to the Council for nomination. No person recommended shall be reported by the Council as a candidate for election, unless he shall have received a written approval, signed at a meeting of the Council by at least eight of its members. All nominations thus approved shall be read to the Academy at a stated meeting, and shall then stand on the nomination list during the interval between two stated meetings, and until the balloting. No person shall be elected a Resident Fellow, unless he shall have been resident in this Commonwealth one year next preceding his election; and any Resident Fellow, who shall remove his domicile from the Commonwealth, shall be deemed to have abandoned his Fellowship. If any person elected a Resident Fellow shall neglect for one year to pay his admission fee, his election shall be void; and, if any Resident Fellow shall neglect to pay his annual assessments for two years, provided that his attention shall have been

called to this article, he shall be deemed to have abandoned his Fellowship; but it shall be in the power of the Treasurer, with the consent of the Council, to dispense (*sub silentio*) with the payment both of the admission fee and of the assessments, whenever in any special instance he shall think it advisable so to do.

3. The nomination of Associate Fellows shall take place in the manner prescribed in reference to Resident Fellows; and after such nomination shall have been publicly read at a stated meeting previous to that when the balloting takes place, it shall be referred to a Council for Nomination; and a written approval, authorized and signed at a meeting of said Council by at least seven of its members, shall be requisite to entitle the candidate to be balloted for. The Council may in like manner originate nominations of Associate Fellows; which must be read at a stated meeting previous to the election, and be exposed on the nomination list during the interval.

4. Foreign Honorary Members shall be chosen only after a nomination made at a meeting of the Council, signed at the time by at least seven of its members, and read at a stated meeting previous to that on which the balloting takes place.

5. Three-fourths of the ballots cast must be affirmative, and the number of affirmative ballots must amount to eleven, to effect an election of Fellows or Foreign Honorary Members.

6. Each section of the Academy is empowered to present lists of persons deemed best qualified to fill vacancies occurring in the number of Foreign Honorary Members or Associate Fellows allotted to it; and such lists, after being read at a stated meeting, shall be referred to the Council for Nomination.

7. If, in the opinion of a majority of the entire Council, any Fellow — Resident or Associate — shall have rendered himself unworthy of a place in the Academy, the Council shall recommend to the Academy the termination of his Fellowship; and, provided that a majority of two-thirds of the Fellows at a stated meeting, consisting of not less than fifty Fellows, shall adopt this recommendation, his name shall be stricken off the roll of Fellows.

CHAPTER X.

OF AMENDMENTS OF THE STATUTES.

1. ALL proposed alterations of the Statutes, or additions to them, shall be referred to a committee, and, on their report at a subsequent meeting, shall require for enactment a majority of two-thirds of the members present, and at least eighteen affirmative votes.

2. Standing Votes may be passed, amended, or rescinded, at any stated meeting, by a majority of two-thirds of the members present. They may be suspended by a unanimous vote.

CHAPTER XI.

Of Literary Performances.

1. The Academy will not express its judgment on literary or scientific memoirs or performances submitted to it, or included in its publications.

RUMFORD PREMIUM.

In conformity with the terms of the gift of Benjamin, Count Rumford, granting a certain fund to the American Academy of Arts and Sciences, and with a decree of the Supreme Judicial Court for carrying into effect the general charitable intent and purpose of Count Rumford, as expressed in his letter of gift, the Academy is empowered to make from the income of said fund, as it now exists, at any annual meeting, an award of a gold and silver medal, being together of the intrinsic value of three hundred dollars, as a premium, to the author of any important discovery or useful improvement in light or in heat, which shall have been made and published by printing, or in any way made known to the public, in any part of the continent of America, or any of the American islands; preference being always given to such discoveries as shall, in the opinion of the Academy, tend most to promote the good of mankind; and to add to such medals, as a further premium for such discovery and improvement, if the Academy see fit so to do, a sum of money not exceeding three hundred dollars.

STANDING VOTES.

1. Communications of which notice has been given to the Secretary shall take precedence of those not so notified.

2. Resident Fellows who have paid all fees and dues chargeable to them are entitled to receive one copy of each volume or article printed by the Academy, on application to the Librarian personally or by written order, within two years from the date of publication. And the current issues of the Proceedings shall be supplied, when ready for publication, free of charge to all the Fellows and Members of the Academy who desire to receive them.

3. The Committee of Publication shall fix from time to time the price at which the publications of the Academy may be sold. But members may be supplied at half this price with volumes which they are not entitled to receive free, and which are needed to complete their sets.

4. One hundred extra copies of each paper accepted for the Memoirs of the Academy shall be separately printed, of which fifty shall be placed at the disposal of the author, free of charge.

5. Resident Fellows may borrow and have out from the Library six volumes at any one time, and may retain the same for three months, and no longer.

6. Upon special application, and for adequate reasons assigned, the Librarian may permit a larger number of volumes, not exceeding twelve, to be drawn from the Library, for a limited period.

7. Works published in numbers, when unbound, shall not be taken from the Hall of the Academy, except by special leave of the Librarian.

8. Books, publications, or apparatus shall be procured from the income of the Rumford Fund only on the certificate of the Rumford Committee, that they, in their opinion, will best facilitate and encourage the making of discoveries and improvements which may merit the Rumford Premium.

9. The annual meeting shall be holden at half-past three o'clock, P.M. The other stated meetings at half-past seven o'clock, P.M.

10. A meeting for receiving and discussing scientific communications shall be held on the second Wednesday of each month, not appointed for stated meetings, excepting July, August, and September.

BEQUEST OF COUNT RUMFORD.

THE following letter was addressed by Count Rumford to Hon. John Adams, July 12, 1796:—

"SIR:—

"Desirous of contributing efficaciously to the advancement of a branch of science which has long employed my attention, and which appears to me to be of the highest importance to mankind; and wishing at the same time to leave a lasting testimony of my respect for the American Academy of Arts and Sciences,— I take the liberty to request that the Academy would do me the honor to accept of Five Thousand Dollars three per cent stock in the funds of the United States of North America, which stock I have actually purchased, and which I beg leave to transfer to the Fellows of the Academy, to the end that the interest of the same may be by them, and by their successors, received from time to time, forever, and the amount of the same applied, and given once every second year, as a premium to the author of the most important discovery, or useful improvement, which shall be made and published by printing, or in any way made known to the public, in any part of the continent of America, or in any of the American islands, during the preceding two years, on Heat or on Light; the preference always being given to such discoveries as shall, in the opinion of the Academy, tend most to promote the good of mankind.

"With regard to the formalities to be observed by the Academy in their decisions upon the comparative merits of those discoveries, which, in the opinion of the Academy, may entitle their authors to be considered as competitors for this biennial premium, the Academy will be pleased to adopt such regulations as they in their wisdom may judge to be proper and necessary. But in regard to the form in which this premium is conferred, I take the liberty to request that it may always be given in two medals, struck in the same die; the one of gold, and the other of silver, and of such dimensions that both of them together may be just equal in intrinsic value to the amount of the interest of the aforesaid Five Thousand Dollars stock during two years;—that is to say, that they may together be of the value of Three Hundred Dollars.

"The Academy will be pleased to order such device or inscription, to be engraved on the die they shall cause to be prepared for striking these medals, as they may judge proper.

"If during any term of two years, reckoning from the last adjudication, or from the last period for the adjudication of this premium by the Academy, no new discovery or improvement should be made, in any part of America, relative to either of the subjects in question (Heat or Light), which in the opinion of the Academy shall be of sufficient importance to deserve this premium, in that case it is my desire that the premium may not be given, but that the value of it may be reserved, and, being laid out in the purchase of additional stock in the American funds, may be employed to augment the capital of this premium; and that the interest of the sums by which the capital may from time to time be so augmented may regularly be given in *money*, with the two medals, and as an addition to the original premium, at each succeeding adjudication of it. And it is further my particular request that those additions to the value of the premium, arising from the occasional non-adjudications, may be suffered to increase without limitation.

"With the highest respect for the American Academy of Arts and Sciences, and the most earnest wishes for their success in their labors for the good of mankind,

"I have the honor to be, with much esteem and regard,
"Sir,
"Your most obedient, humble servant,
"RUMFORD.

"*London*, July 12, 1796."

The stocks mentioned in this letter were received by the Academy in 1797. In 1831 a Bill in Equity was brought before the Supreme Judicial Court of Massachusetts, praying relief in the matter of the Rumford Fund; and thereupon the following decree was made by that Court:—

DECREE. — *Supreme Judicial Court, March Term,* 1832.

In Equity between } The American Academy of Arts and Sciences, Complainants,
The President and Fellows of Harvard College, Defendants.

"The cause coming to be heard upon the Bill and answer, by agreement of the parties, — the substance of the plaintiffs' Bill appeared to be that

"Benjamin, Count Rumford, in his lifetime, made a donation to the plaintiffs of five thousand dollars in the three per cent stocks of the United States, as a testimony of his respect for the American Academy of Arts and Sciences, and for the purpose of promoting by premiums, to be adjudged biennially by them, for the making of such discoveries relating to light and heat, as should, in the opinion of the plaintiffs, tend most to promote the good of mankind, and which should be made and published in the American continent or islands within the two years next preceding the awarding of such premium, and directing the surplus income and accumulation of said fund to be invested in the stock of the United States, and the income thereof added to the said premiums. But it is alleged that the mode of awarding said premiums pointed out by the donor cannot usefully, nor without defeating the general intent of the donor, be strictly complied with; and that in consequence thereof no premiums have been yet awarded, but the said fund has, by the addition of the income thereof, accumulated to the sum of nearly twenty thousand dollars; and the income thereof for two years has become too large for a proper premium for such discovery; and that the same cannot longer be conveniently invested in the stocks of the United States. Therefore, that the plaintiffs may be authorized to dispose of the surplus income of said funds in other modes adapted to promote the general intent of the donor, and to invest said fund in more convenient securities.

"Whereto, the defendants, by answer, admit the material facts set forth in the Bill, but allege that, as residuary legatees of said Benjamin, Count Rumford, they are entitled to have paid over to them, for the use of the Rumford Professorship, founded by said Count Rumford, at said University, any portion of said fund, and of the accumulation and interest thereof, which cannot be applied in the hands of the complainants to the execution of the general intent of said donor.

"The cause having been argued by counsel, and fully considered, it appears to the Court that the complainants have not done any act, or neglected or omitted to do anything, whereby they have forfeited, waived, or renounced the said donation, and that the President and Fellows of Harvard College have no right, as residuary legatees of Count Rumford, or otherwise, to claim the same, or any part thereof. It further appears that the said donation was made to the American Academy for a general purpose of charity, that, namely, of promoting a useful branch of science for the benefit of mankind; that the Academy accepted the same, upon the terms stated, and for the purposes contemplated by said donation, and are now under obligation to carry the general intent of the donor into effect, as far as it is practicable to do so. It further appears, that, in consequence of the impediments set forth in the Bill, it is impracticable for the Academy to carry the general charitable intent of the donor into effect in the exact and precise mode specified by him; but, considering the general and primary intent of Count Rumford to have been to awaken and stimulate the ingenuity, and encourage the researches and experiments of individuals on the continent or the islands of America to make important discoveries or useful improvements upon the subjects of Light and Heat, and to cause them speedily to be published for the good of mankind, it does appear to the Court, that it is quite practicable for the Academy to accomplish and carry into effect the general charitable intent and purpose of Count Rumford by some slight alterations in the mode particularly prescribed by him for carrying the same into effect. It also appears to the Court that it would tend to promote the general charitable intent of the donor to allow the complainants to invest the principal of the said fund in some safe and productive securities other than the stocks of the United States.

"Whereupon, it was ordered by the Court that the matter be referred to one of the Masters in Chancery, to report a scheme for carrying into effect the general charitable intent and purpose of the donor, conformably to the prayer of the plaintiffs' Bill; and now John B. Davis, Esquire, one of the Masters in Chancery for the County of Suffolk, has reported a scheme in pursuance of said order, which, being heard and considered by the Court, and the same appearing reasonable and conformable to the general intent of the donor, is accepted; and it is therefore by the Court ordered, adjudged, and decreed, for the reasons set forth in the Bill, that the complainants be, and they are by the authority of this Court, empowered to make from the income of said fund, as it now exists, at any annual meeting of the Academy (instead of biennially, as directed by the said Benjamin, Count Rumford), award of a gold and silver medal, being together of the intrinsic value of three hundred dollars, as a premium to the author of any important discovery or useful improvement on Light or on Heat, which shall have been made and published by printing, or in any way made known to the public, in any part of the continent of America, or any of the American islands, preference being always given to such discoveries as shall, in the opinion of the Academy, tend most to promote the good of mankind; and to add to such medals as a further reward and premium for such discovery or improvement, if the complainants see fit so to do, a sum of money not exceeding three hundred dollars.

"And it is further ordered, adjudged, and decreed, that the complainants may appropriate from time to time, as the same can advantageously be done, the residue of the income of said fund hereafter to be received, and not so as aforesaid awarded in premiums, to the purchase of such books and papers and philosophical apparatus (to be the property of said Academy), and in making such publications, or procuring such lectures, experiments, or investigations, as shall in their opinion best facilitate and encourage the making of discoveries and improvements, which may merit the premiums so as aforesaid to be by them awarded. And the books, papers, and apparatus so purchased shall be used, and such lectures, experiments, and investigations be delivered and made, either in the said Academy or elsewhere, as the complainants shall think best adapted to promote such discoveries and improvements as aforesaid; and either by the Rumford Professor of Harvard University, or by any other person or persons, as to the complainants shall from time to time seem best.

"And it is further ordered, adjudged, and decreed, that the said fund, or any part thereof, may be from time to time invested by the said complainants either in notes, stocks, or debts of the United States, or of the Commonwealth of Massachusetts, or of the City of Boston, or in stock of the Bank of the United States, or of any bank in this Commonwealth, or in notes or bonds secured by pledge of any of said stocks, or by mortgage of real estate in this Commonwealth, or may be deposited in trust, and on interest, with the Massachusetts Hospital Life Insurance Company."

MEMOIRS

OF

THE AMERICAN ACADEMY

OF

ARTS AND SCIENCES.

CENTENNIAL VOLUME.

VOL. XI. — PART II. — NO. I.

CAMBRIDGE:
JOHN WILSON AND SON.
University Press.
1885.

Author's copies distributed in June, 1883.

THE TORTUGAS AND FLORIDA REEFS.

BY

ALEXANDER AGASSIZ.

READ NOV. 15, 1882.

CAMBRIDGE, JUNE, 1885.

MEMOIRS.

I.

Explorations of the Surface Fauna of the Gulf Stream, under the Auspices of the United States Coast Survey. — II.[1] *The Tortugas and Florida Reefs.*

By ALEXANDER AGASSIZ.

(Published by permission of Carlile P. Patterson and J. E. Hilgard, Superintendents United States Coast and Geodetic Survey.

Presented November 15, 1882.

All naturalists who have visited the Florida Reefs have felt the difficulty of applying Darwin's theory of reef formation to the peculiar conditions existing along the Straits of Florida. Agassiz, Le Conte, and E. B. Hunt have each in succession attempted to explain, from a different standpoint, the mode of formation of the Florida Reefs. Agassiz stated, and his statement was afterward confirmed by Le Conte, that the Florida Reefs had a distinctive character, and could not be explained by subsidence, to which cause Darwin had ascribed the formation of barrier reefs in general. The report of Agassiz on this subject, presented to Professor Bache in 1851, has been republished in full in the Memoirs of the Museum of Comparative Zoölogy. In this report he has shown, not only that the southern extremity of Florida is of comparatively recent growth, but that the causes by which it has for the greater part been built up are still going on, and that we have a specimen or sample as it were of the past action in the mode of growth of the present reef, keys, and mud flats. He showed that the whole southern portion of Florida is built of concentric barrier reefs, which have been gradually cemented into a continuous sheet of land by the accumulation and consolidation of mud flats between them, — a process

---

[1] For No. I. see Bulletin of the Museum of Comparative Zoölogy, Vol. IX. No. 7, p. 252. 1882.

which is now going on between the Florida keys and reefs from Cape Florida to the Tortugas, and must end in transforming them, in like manner, into a continuous tract, to be connected eventually with the mainland.

In Agassiz's report no attempt was made to explain the substructure of the peninsula upon which the reef corals grow. Le Conte, however, attributed this substratum to the mass of material brought along by the Gulf Stream. He believed that the Gulf Stream then ran parallel with the line of the present peninsula, and that the substratum was formed by the heaping up of these loose materials along that line. All the later investigations show, however, that the Gulf Stream never followed this course. Then, as now, it swept across, and not parallel with, the line of the peninsula, and though it undoubtedly assisted in the building up of Forida, it simply brought then, as it does to-day, the food, or the greater part of the food, consumed by the animals living on the Bank of Florida. These animals supply, by their growth and decay, the building material for the great Florida Bank. No doubt, the floating animals brought by the Gulf Stream add something beside to the mass of the bank itself; but they are chiefly consumed by the animals living upon it.

The curve of the Florida Reef (Plate VI.) along the Gulf Stream is due in great measure, as Hunt shows, to a counter current along the reef running westward. This current is known to all navigators, and, though ill-defined at Cape Florida, it becomes stronger and wider as it goes west. It has a width of at least ten miles at Key West, and of twenty miles at the Tortugas. This is clearly shown by the mass of surface animals driven along upon this westerly counter current by the southeasterly winds.

The tides set strongly across the reefs, and through the channels between the keys, the flood running north and the ebb south. When storms occur, the fine silt of the bank, made up of coral sand from the reefs, is taken into the bay back of the keys and deposited there. The counter current then carries this to the westward, and thus material has gradually been added to the flats. As Hunt has already noticed, tides and currents have undoubtedly been the principal agents here. That this material has not been brought by the Gulf Stream from the mouth of the Mississippi, is shown by the fact that no trace of Mississippi mud has ever been found in any of the innumerable soundings taken to the eastward of the Mississippi, or more than a hundred miles from its mouth. It is also probable that the action of the waves from the southeast, in forming a talus of coarser material, does not penetrate below one hundred fathoms, and everything once fixed below that depth has its final character. The line of keys seems to be formed by the waste of the exterior present reef, rather than by the remains of an older anterior reef. At the Tortugas, the contrary seems to be the case; but this perhaps is due to the fact that the strong currents which sweep over the reefs, and have excavated the Southwest Channel, have also established conditions favorable to the growth of corals on both sides of this channel, and that the two lines of keys are due to this cause. Had the currents run only from the Southeast through the Northwest Passage, larger keys, separated by channels running north and south, would then have been formed.

I shall first show by an examination of the Tortugas how far the explanations given by Agassiz, Le Conte, and Hunt are satisfactory as regards the formation of the group of islands making the extremity of the reef, and shall then attempt, by the help of the dredging operations of the "Blake" along the Florida Bank, to reconstruct the past history of the peninsula in its southern portion. Beginning with an account of the formation of the present Reef, based upon the knowledge obtained by a careful survey of the Tortugas, I shall then proceed to the elucidation of the structure of the peninsula itself.

The Tortugas (Plate I.) are situated at the very extremity of the slope upon which the line of the Florida Reefs has been built up. They form the most recent of the cluster of Florida Reefs, and have not as yet been transformed into the normal coral reef characteristic of the whole line extending from the Rebecca Shoal and Marquesas to Cape Florida. There is as yet nothing at the Tortugas corresponding to the extensive mud flat stretching uninterruptedly a few feet below the surface of the water, to the northward of the line of keys (Plates X., XI.). The northern part of this flat, from Cape Sable to Key Biscayne, is fringed on the southeast face by the line of narrow keys reaching from Cape Florida to Bahia Honda (Plate VI.). In the oldest part of the reef, the bay to the north of the keys, the waters of which once undoubtedly covered the whole space between Pine Keys and Cape Sable, has little by little been filled up and transformed for the greater part into the wide shallow mud flats now extending over that area. Next comes, from the Pine Keys to Rebecca Shoal, a comparatively more recent portion of the reef, in which the northern extremities of the keys rise somewhat higher above the general level of the mud flats. These two adjoining regions of flats and keys run parallel to the main reef, at a distance of from one to nine miles from the outer line of reefs; the reef that is, *par excellence*, over the whole surface of which the living corals still prosper. Farther yet to the westward, at a distance of fifteen miles from the western extremity of the outer parts of the reef, rise the Tortugas. In this group a condition of things prevails at the present day, which must have been repeated over and over again from the time when the Florida Reef formed but an insignificant point south of the line extending from Cape Sable to Key Biscayne, until it reached the extremity of the present continuous mud flat, about ten miles to the west of the Marquesas. As is well shown on the Coast Survey maps, the mud flats, keys, and reef dip as a whole to the southwest, as does also the Florida plateau to the westward of the Marquesas. It is only upon such parts of this plateau as from some cause or other have attained a sufficient elevation to allow corals to flourish, that the reef may be expected to extend. The knoll rising above the general level upon which the Tortugas have little by little been built up, is such an area, and such also is the patch to the westward of the Tortugas, upon which, as I shall show hereafter, an incipient coral reef is already forming, at a depth of a little less than twenty fathoms (Plate I.). It is not difficult to go back to a time when the great mud flats of Florida did not exist. In their place was a steep slope, such as we now find to the west of the Tortugas. Following the comparison backward, it is easy to imagine how, little by little, from the existence of the prevailing easterly winds and currents, the materials coming from the small outside reefs and held in suspense were little by little driven to the westward, accumulating finally upon what was then the extremity of the great Florida Bank. There they gave rise to knolls similar to those upon which the Tortugas have been built. From the moment these knolls attained a sufficiently favorable elevation for the growth of corals, a western reef was at once formed, holding to the small Florida Reef then existing very much the same relations as the Tortugas at the present day hold to the great Florida Reef. Again, by the same agencies, the channels which once undoubtedly ran back into the mud flats to the north of the oldest keys were gradually closed; such channels as are still open in part or wholly in the more recent and westerly portions of the reef, as, for instance, the entrance to Key West Harbor, running from the south to the north across from the reef to the mud flats. In like manner these channels and those which form an extensive strait on the most recent part of the reef between Rebecca Shoal and the Tortugas, will in time disappear, and become, in consequence of the extension of the mud flats beyond Rebecca Shoal, narrow channels, like those of Key West, of the Pine Keys, and of the Marquesas. By this time there will also have been formed an extension of the outer reefs along the twenty-fathom line, connecting the Tortugas with the present reef, and only broken here and there by passages similar to those already existing along the reef, by which vessels find free access to the middle passage between the reef and keys. These channels are kept open by the same tidal agencies as are now more powerfully at work at the Tortugas, but which have gradually diminished in force from the Pine Key Channel to the northward. The depth of the passage between the Tortugas and Rebecca Shoal allows a larger and stronger body of water to pass through that channel than through any other.

It has been clearly proved by Hunt that the extensive flats to the northward of the keys have been formed by the agency of the tides, the whole triangular space between the Rebecca Shoal and Cape Sable being filled up with silt. The flood running in a northerly and the ebb in a southerly direction, the tides in their alternation hold in suspense the silt which they wear away from the reef or from the shores of the keys. During storms this floating silt is driven either on to the flats to the north of the keys, or on to the slope of the reef toward the Gulf Stream. An examination of the present condition of the Tortugas, and of the mud flats beyond the Marquesas, gives us a very simple explanation of the formation, and gradual extension westward to its present limits, of the small reef originally existing only as a diminutive spit, but gradually spreading to the southwest from Cape Florida until it reached its present gigantic proportions.

The Tortugas show us, as will be seen, how the reef was actually formed, while the extension of the mud flats beyond the Marquesas explains how the bottom is prepared and gradually raised to a level at which corals will flourish. One other condition was, however, essential to the development of the coral reef, that of the existence of a powerful current, such as the Gulf Stream, bringing an immense quantity of pelagic animals to serve as food for the corals found along its path. There is practically no evidence that the Florida Reef, or any part of the southern peninsula of Florida which has been formed by corals, owes its existence to the effect of elevation; or that the atolls of this district, such as those of the Marquesas or of the great Alacran Reef, owe their peculiar structure to subsidence.

It cannot be denied that the backbone of the Florida peninsula was first produced by a fold of the earth crust in an earlier geological period. Smith and Hilgard have also shown that such a fold or folds formed the axis which has raised a part of the northern base of the peninsula to a height of something less than two hundred feet, and that this axis, which has still, at the latitude of Lake Okeechobee, an elevation of about forty feet, but sinks gradually as we go south, was formed before the Vicksburg limestone age, while on either side of it are deposited the more recent limestones which have given Florida its present width. They have pointed out, moreover, as a secondary result of this folding, the formation of an immense submarine plateau directly in the track of the Gulf Stream, which has been gradually built up since that time by the accretions of the solid parts of Mollusks, Echinoderms, Corals, Alcyonoids, Annelids, Crustacea, and the like, which have lived and died upon it, thus furnishing the limestone for the gradual completion of the peninsula. No one who has not dredged near the hundred-fathom line on the west coast of the great Florida Plateau can form any idea of the amount of animal life which can be sustained upon a small area under suitable conditions of existence. It was no uncommon thing for us to bring up in the trawl or dredge large fragments of the modern limestone now in process of formation, consisting of the dead carcasses of the very species now living on the top of this recent limestone. To the westward of the western shore line, Florida now stretches out as an immense submarine plateau, forming, as the sections show, a huge tongue coated or veneered only by coral limestone over its very top. The whole of the peninsula of Florida south of St. Augustine, as far as Tampa Bay, has probably been built up in this way, from north to south, of limestone somewhat older than the reef limestone. The plateau, judging from the inclination of the axis, has but a slight southward dip until we reach the southern extremity of the peninsula, where the fall is more rapid toward the outer reef.

The whole of the eastern and western edges of Florida consist of recent limestones, the immediate predecessors of the present limestone now forming on the western and southern slopes of the great Florida Plateau. The early dredgings of Mr. Pourtalès, in 1867 and 1868, developed on the Gulf Stream slope off the Florida reefs an extensive rocky plateau (Pourtalès Plateau) from a depth of about ninety fathoms to about two hundred and fifty fathoms. The rock of which this plateau is built consists of the same species of corals and shells as those now living upon it, to which it owes its formation. A similar sea-bottom is found on the north side of Cuba, but with a much steeper slope. These fringing limestones also formed the southern extremity of Florida at a time when the northern part of the Everglades had perhaps been built up to a level favorable for the growth of coral reef. In this northern portion of the Everglades alone can we confidently speak of the first concentric reefs, which have little by little built up Florida toward the south. It seems highly probable that on the remainder of the peninsula north of the Everglades both the newer and older limestones were built up by the same agencies as are now at work on the Florida Bank. There are to-day other submarine banks which undoubtedly owe their origin to similar agencies. The great bank to the east of the Mosquito coast, which practically extends to Jamaica, has probably been formed in the same way as the Yucatan and Florida Banks; that is, by the gradual decay of the animals subsisting in great abundance upon its slope, and fed by the pelagic materials which the currents and the prevailing winds bring to the bank. All the reefs on the south coast of Cuba between the Isle of Pines and the shore to the east and west may have a similar origin. Among the West India Islands the barrier reefs of the windward side are built upon plateaux of a similar structure. The Basse Terre of Guadeloupe is a fine example of such a plateau, which has been elevated slightly above the level of the sea. At Barbados the whole shell of the island consists of a series of terraces, which have been successively lifted by the trachytic centre forming the nucleus of the island. These terraces are entirely composed of limestone formed of the species of Mollusks and Radiates now living in the West India seas.

While there is thus undoubted evidence that a great part of the shore line of the northeast extremity of South America has been washed away, yet there is also evidence that the lines of the bank connecting the lesser West India Islands have been built up by agencies similar to those which have formed the Yucatan and Florida Banks, except that these latter have been formed around the volcanic islands or folds extending along the eastern edge of the Caribbean Sea. In some cases these banks have been elevated after the existing condition of things was in force; in others their elevation dates back to the period when the separation of the Caribbean from the Pacific took place, at the time of the closing of the Isthmus of Panama. Evidence of this action is found in the elevated coral reefs and the raised earlier tertiary and later cretaceous deposits of the West Indies and Central America.

Nowhere do we find better examples than in the West India Islands of the formation of submarine banks in connection with volcanic peaks. A great number of peaks of volcanic origin have risen nearly to the surface of the sea, or above it, and serve as the foundation of great submarine banks. It is well known, also, that the "Challenger" and "Tuscarora" soundings have developed a number of submarine elevations, covered by deposits of Pteropods and Globigerina ooze, forming extensive banks serving as foundations for barrier reefs and atolls, while the volcanic substratum has been completely hidden. In the West Indies, as at Martinique, there are volcanic peaks rising to a height of over four thousand feet; on their windward side are extensive submarine plateaux, formed, I imagine, by agencies similar to those to which we ascribe the formation of the Yucatan and Florida plateaux. Whenever such plateaux have reached on their windward side the level at which corals prosper, there coral reefs spring up and flourish. Side by side with such conditions we find plateaux at lower levels, under a greater depth of water, covered only by the Invertebrates living upon their surface, — as is the case, for instance, in the northern extremity of the plateau of the Grenadines. These plateaux have probably never risen to the surface. We have also the still older phenomenon of such islands as Barbados, where the terraces formed by the raised coral reefs mark the successive elevation of the volcanic cone; or we may have still another combination, like that of Guadeloupe, where a high volcanic peak forms the main island, an elevated plateau forming the Basse Terre with a growing coral reef to the windward of the latter.

The fact that these great submarine banks of modern limestone lie in the very track of the great oceanic currents sufficiently shows that these currents hold the immense quantity of carbonate of lime needed in the growth of the bank. Its amount has, besides, been actually measured by Murray. He has shown that, if the pelagic fauna and flora extend, as the experiments carried on by the "Challenger" and the "Blake" seem conclusively to prove, to a depth of one hundred fathoms, we should have sixteen tons of carbonate of lime for every square mile one hundred fathoms deep. But the greater the depth at which these plateaux begin to form, the less rapid must be their formation. The fact that the deeper part of the ocean, below three thousand fathoms, does not contain any of the larger shells of pelagic type, can be readily explained on the supposition that, being thinnest, like Pteropod shells, they present a large surface to the action of the carbonic acid, which is most abundant in deep water. Attacked as soon as they reach the bottom by this action, these shells of thinnest surface are reduced to a bicarbonate, and are carried off in solution. They do not, therefore, appear at these greater depths, and are indeed rarely to be found below two thousand fathoms. The thicker-shelled Foraminifera extend to a greater depth, not because they are of different chemical composition, but because their greater amount of substance yields less easily to the action of the acid. At shallower depths the solvent action of carbonic acid must be far less efficient, on account of the rapid accumulation of dead siliceous and calcareous shells of Foraminifera, Sponges, Hydroids, Corals, Halcyonoids, Mollusks, Polyzoa, Echinoderms, etc., which must long have lived upon the bank before they had by their accumulation brought it to a level at which coral reefs could begin to grow.

The bathymetrical sections (Plate VII.) of the peninsula of Florida to the eastward into the trough of the Gulf Stream are very different from those taken on the western side of the peninsula. Proceeding northward from Cape Florida, you pass out of the action of the current from the Straits of Bemini, where the velocity of the Gulf Stream is the greatest. As soon as you reach a latitude at which the trade winds do not blow, you come gradually upon the usual comparatively gentle slope off shore, showing less traces of disturbance either from currents or from the action of the prevailing winds. Judging from what I have seen of the east coast of the peninsula of Florida, the shore line deposits, such as the Coquina of St. Augustine and the shelly beaches of Indian River, seem to indicate the presence in deep water of a limestone deposit formed of the detritus of Mollusks, Annelids, Starfishes, and Sea-urchins. There are but few corals, occasional patches of reef-builders, but no extensive reefs; but this is a difficult point to decide even at Key West. Indeed, all along the line of the reefs it would be difficult to decide to-day whether the reefs have been formed, like the Marquesas Keys, merely by the accumulation of detrital matter driven to the westward and northward, or whether the Mangrove Keys and the reefs really indicate the old lines of a reef similar to the one now in full activity on the northern edge of the Gulf Stream, parallel to the main line of keys. The absence of the more delicate shells from limestone in the formation of which they must nevertheless have shared, is explained by the solvent action of carbonic acid upon them, and by the deposition of carbonate of lime as a cement. A comparison of the structure of Loggerhead Key at the Tortugas with that of the Mangrove Islands and the main keys, shows us the difficulty of deciding these points. At Loggerhead Key we have a shore line made up of brecciated and oölitic coral limestone, fully as characteristic as any similar shore line on the older keys like Key West (Plate XII.). Yet we still find on the southern, eastern, and northern sides of Loggerhead an active growth of reef-building coral, while other parts of the island and some of the flats, if covered by mangroves, could not be distinguished by their structure from the genuine mangrove islands on the flats to the north of the inner line of keys along the main reef (Plates X., XI.).

We must be careful to distinguish the line of islands running from the mouth of the St. John to Cape Florida, parallel with the coast of Florida, from the line of islands forming the Florida Keys. The latter seem at first glance to be the continuation of the former; but this is not the case, their móde of formation, as well as their geological structure, being radically different. As has long been pointed out by H. D. Rogers, the line of narrow islands to the eastward of Florida belongs to the series of coast islands lying parallel to the coast from Long Island to Florida, and extending around the whole Gulf of Mexico. They all seem to have been formed by the same causes, perhaps by the action of currents along the continental shores forming lines of deposit of but little width, separated from the mainland by a shallow channel. Some of these islands have been slightly elevated at a comparatively recent period. This is especially the case with the islands along the east coast of Florida,— Anastasia Island, and those running south to Cape Florida, separating Indian River from the Atlantic Ocean. In all these we find the so-called Coquina of St. Augustine raised from ten to twenty feet above the level of the sea at such points as Anastasia, Merritt's, and Worth Islands, showing all along the east shore of Florida a very recent formation of shell *débris* or breccia very similar to the formation now going on in the lagoons near Venice. This bed of shell breccia was probably deposited after the low backbone of the peninsula, extending from Southern Georgia and Alabama to the northern part of Lake Okechobee and the Everglades perhaps, had been raised, and when the peninsula of Florida from the St. John to the eastward was below the level of the sea at a shallow depth. At any rate, it seems plain from recent evidence that no trace of reef-building corals exists on the east coast north of Cape Florida. Mr. Dietz is inclined to look upon the formation of these islands as due to the action of the waves. But there seems to be nowhere, as is well stated by Rogers, any deposit of the kind going on now; and when such masses of shells are thrown up on beaches, the tendency is strong to consolidate from fragments to the concrete form known as Coquina.[1] The mode of formation does not, however, seem adequately explained by Rogers from the action of currents acting along the coasts. These currents must have flowed over a wide plateau, and have supplied the large amount of food needed for the development of a large and thriving bank of Mollusks and other Invertebrates. As soon as these growing colonies had risen high enough to form banks parallel to the shores, they were in their turn cut off and isolated from the shore by the action of the tides and currents, which must then have begun to deepen the channels intervening between the bars and the mainland. They must also have forced their way across to form the shifting inlets, such as Mosquito Inlet, etc., so characteristic of the channels leading into these inland waters along our whole Southern Atlantic coast. The dip of the Coquina bed to the westward is well shown by the borings of Artesian wells at Palatka. I was informed by the contractor that he met the Coquina beds at a depth of about forty feet, when he reached a mass of clay, which in its turn was underlaid by pebbles resembling the small pebbles found on flats off a rocky shore. Possibly this mass of clay was formed by the silt of the Gulf Stream at a time when it flowed over the low ridge of Central Florida, before that ridge had risen to form a dividing line between the two plateaux, which must have extended, the one to the westward much as it now is, while the other undoubtedly extended in some localities north of Cape Canaveral somewhat to the eastward of the present shore line of Florida.

All this evidence tends to show that the coral reefs had little if anything to do with the building up of the peninsula of Florida north of Cape Florida. The present

---

[1] Fourth Report, British Association for 1834–38, p. 11.

line of reef is indeed probably the only one which has played any important part in the formation of land south of the line of the present southern extremity of the peninsula of Florida. There seems, however, some reason to believe that a line of reefs, or perhaps two lines not very distant from each other, once stretched along the southeastern end of the Everglades before the present reef began to extend westward. Judging from the sections shown by the maps, the growth of the present reef, as fast as the mud flats were formed to the south of it, has been altogether in that direction (Plate VIII.).

The Bahamas, the San Pedro and Yucatan Banks, have probably all been formed by a similar process, — by the accumulation of limestone either upon an early fold of the earth's crust, or upon a volcanic plateau, or upon a foundation of slower growth from great depths. In Yucatan we can actually descend into the bank itself through any one of the aguadas, or caverns, found everywhere in the northern part of that country. Many of these caverns extend to a considerable depth. One of them, that of Bolonchen, has a depth of seventy fathoms, the whole formation consisting of recent limestone entirely composed of species of Invertebrates now living on the Yucatan Bank. In Yucatan, as in Florida, we find a low ridge of limestone, somewhat older than that of the coast, extending across the peninsula. The uplifting of this ridge has caused the slight undulations of level traceable throughout Yucatan, at a distance of from twenty to thirty miles from the coast, and running nearly at right angles to it. Judging from its fossils and lithological characters, the limestone of which this ridge is formed is identical with the so-called Vicksburg limestone of the central backbone of Florida. I have already attempted to show, in my letter No. 1 (Bull. M. C. Z., V., No. 1), containing an account of the great Alacran[1] Reef on the Bank of Yucatan, that we need not refer the atoll-shaped form of this reef (Plate V.) to the subsidence of the Yucatan Bank as a whole, since the action of the prevailing winds and currents would account for all the existing phenomena. The decay of the animals living upon the great plateau, added to the deposition of all the animal life brought to it

---

[1] The map of Alacran on Plate V., copied from one of the Hydrographic Office charts, gives an excellent idea of this magnificent reef, its eastern face forming a great arc of a length of about twenty miles, exposed to the full sway of the easterly winds. The huge breakers pound incessantly upon this steep face of the reef, and drive all the silt to the westward. This silt has already completely killed the corals on the eastern faces of the long, narrow sandy islands forming the western chord of the reef. Between them and the walls of coral heads still runs an irregular channel, varying in depth from one to six fathoms, and connected with the open water by narrow channels on the southern face of the reef. The section of the reef shows that, like the Tortugas, it has been built up from the general level of the Yucatan Plateau, rising gradually from a depth of about thirty fathoms until it reached the depth at which corals can flourish, when it shot up more vertically to form the present cone of the reef. The western slope is not so steep as the eastern, and the silt below the twenty-fathom line is deposited on a much more gentle slope than on the eastern face.

by the currents, would explain a gradually increasing elevation of the surface till the level was reached at which reef-building corals can flourish, and at which a reef would naturally be formed. Darwin has noted the close resemblance between encircling barrier reefs and atolls. It seems to me that the structure of the Marquesas[1] (Plate V.) and of Alacran proves conclusively that not one point of difference exists between a barrier reef and an atoll. Darwin has also called attention to the fact, that in shallow seas, such as the Persian Gulf and parts of the East Indian Archipelago, the reefs lose their fringing character and appear as irregularly scattered patches, often covering a considerable area; and observes that many reefs of the West Indies have been formed in like manner upon large and level banks lying a little beneath the surface, — banks which he believes to have been formed by the accumulation of sediment. Such patches of reef-building corals would seem, from their analogy with the Tortugas, to be the beginning of more extensive reefs.

Judging from my examination of the Tortugas reefs, it would seem that corals do not thrive below a depth of from six to seven fathoms. It is, of course, impossible to determine whether that is their bathymetrical limit, or whether they are killed from the accumulation of ooze in the channels and adjacent slopes. We find them confined, however, to the same shallow depths, along the whole of the main reef to the northward (Agassiz). Captain Moresby also showed that at a depth of ten fathoms in the Maldive and Chagos archipelagoes the masses of living coral are scattered at greater distances separated by patches of smooth white sand, and that at a slightly lower depth even these patches merge into a smooth, steep slope wholly bare of coral. All the evidence accumulated by Dana, Ehrenberg, Quoy and Gaimard, tends to show that the limit of reef-building corals is found at about twenty fathoms. On the Yucatan, as on the Florida Bank, the conditions favorable for coral reef growth have

---

[1] The plan and section of the Marquesas Keys on Plate V. show the formation of the keys on a knoll rising from the general platform of the surrounding reef plateau. This knoll has undoubtedly been built up, as were the Tortugas, from the remains of the corals which once lived upon its face and surface until the formation of the outer reef shut out the prevailing easterly winds, and the corals were killed from the accumulation of silt upon them. The filling up of a lagoon like that of the Marquesas must be a slow process, for we find the water of the inner lagoon deeper than that of any other part of the reef immediately surrounding the outer slope. We can imagine that when the outer ring of the reef surrounding the inside lagoon is once connected, or nearly so, the enclosed calm area is so placed as to be subject to but few disturbing agencies, and is practically excluded from receiving any appreciable amount of sediment from the water of the outer reef, the lagoon connecting with the surrounding waters only by the narrow passages forming the channels between the lagoon and the main channel. Whether the removal of the dead coral rock from the interior of the lagoon of an atoll by the action of the current through the narrow connecting channels, and by the solvent action of the carbonic acid, will alone explain the cause of the great depth of the interior lagoon, seems somewhat doubtful. The mud of the interior of the Marquesas atoll was found to be calcareous, as is practically all the mud which forms the extensive mud flats to the northward of the keys. This mud is, however, generally covered by a thin dark-colored layer of decomposed vegetable and animal matter. The Marquesas are covered by a thick growth of mangroves.

been produced, not by the uplifting of the continent, but by the gradual rising of the bank itself into suitable depths in consequence of the accumulation of animal *débris* upon it. That level once attained, reef-building corals would first establish themselves on such spots as were most favorably situated, with reference to currents and prevailing winds, both of which are essential to their healthy growth, and thus the reef would be begun.

How far the growth of corals is affected by such local conditions is perhaps nowhere better seen than in the smaller West Indian islands. On the eastern side, exposed to the prevailing trade winds and washed by the great equatorial currents, the corals flourish, while on the lee side they do not exist at all. The whole eastern coast of Honduras, of Yucatan, and of Venezuela, exposed to the same action and washed beside by the Gulf Stream, is studded with coral reefs. To the action of the Gulf Stream on the south coast of Jamaica and of Cuba we must ascribe the presence of extensive coral reefs, and to the same cause is undoubtedly due the great San Pedro Bank. The fringing reef which skirts nearly the whole northern coast of Cuba is in a less flourishing condition than the Florida reef on the opposite shore, which is reached not only by the main current of the Gulf Stream, but also by the prevailing winds. For a similar reason, corals are found alive only on the edges of the Great Bahama, where they are subjected to the beneficent action either of currents or of winds, driving the silt clear of the growing corals, and bringing an abundant supply of food. The same causes which have formed the great mud banks to the northward and westward of the Florida Reef have, in the case of the Bahama Banks, formed the immense sand flats and shallows which are fringed by living corals on the east and west. They owe their existence, on the one side, to the wash of the northerly trend of the great equatorial current and to the action of the trades; on the other, to the clearing action of the Gulf Stream. It must also be remembered that the Bahama Plateau was originally joined to Florida, as part of the great fold which built up the framework of that peninsula, and that it was also connected at one time with the island of Cuba. It was also united with the reefs, now elevated to eleven hundred feet, which joined the eastern and western islands in more recent geological times, and formed, before the Tertiary, the two extremities of Cuba. On the southern side the reefs are still in full activity, while on parts of the northern coast, in the vicinity of Havana, they have been elevated to a height of no less than one thousand or eleven hundred feet, while the present barrier reef of the north shore of Cuba forms an immense reef, extending nearly without break from Cape San Antonio to the eastern edge of the old Bahama Channel. The Bahama

Plateau we may also fairly assume to have been built up, little by little, from its original level, by the accumulation of limestone formed in great part from the bodies of the mass of animals which undoubtedly flourished upon the great submarine plateau at a time when the Gulf Stream found its way out of the Gulf of Mexico with less velocity than it now has as it passes through the narrow Straits of Bemini. At that time it spread itself fan-shaped over the southern part of Florida and the Bahama Bank, and flowed more gently northerly and easterly along the coast with the additional reinforcement of the westerly equatorial flowing north of the Great Antilles to the eastward of Cuba. The Bahama Banks then probably consisted of a series of banks like Salt Key Bank, separated by channels like the Santarem and St. Nicholas, undoubtedly kept open by the same currents as now form the old Bahama Channel. These channels, like those between the keys on the Florida side, have gradually become filled with the detritus driven into them by the trade winds, till the whole formed the bank in its present state of consolidation. And yet it must not be forgotten that, while in the western part of the Caribbean, the Gulf of Mexico, and Florida a dead level prevails, at Havana, Hayti, and Barbados we have reefs elevated to a great height, and others at considerable elevation on certain of the Greater and Lesser Antilles. The somewhat capricious distribution of coral reefs may perhaps be explained by the action of the great equatorial currents. The larger reefs occur in regions to which these currents bring in the track of their course abundant supplies of food for the reef-building animals. On the eastern coast of Africa, of Central America, or of Australia, for instance, extensive colonies of coral reefs flourish, while on the western coast of the same continents in similar latitudes, but not bathed by such powerful equatorial currents, the supply of food seems insufficient for more than the isolated patches of corals existing there.

Other naturalists, as Semper[1] and Murray,[2] have already attempted to explain the formation of coral reefs, in part at least, on grounds differing essentially from those to which Darwin ascribed them, and similar in the main to those here brought forward. Undoubtedly Darwin's theory of reef formation presents a sound and admirable exposition of the grander causes which have brought about the elevation or subsidence of large tracts to a level favorable for coral growth; but at the time he wrote upon this subject, the formation of these extensive limestone banks, built up by the animals living on the bottom, and constantly strengthened and increased by the attendant phenomena of winds and currents, was little under-

---

[1] Semper, C. Zeits. f. Wiss. Zool., 1863, XIII., p. 558.

[2] Murray, John. Proc. R. S. Edinb., No. 107, 1880, X., p. 505, On the Structure and Origin of Coral Reefs and Islands.

stood. These facts have been brought into notice and emphasized by recent deep-sea explorations. Darwin, however, when examining maps of the West Indies, had been struck by the probable connection between the areas of deposition of the great banks marked upon the charts and the course of the sea currents. He naturally explained the steep slopes abruptly dropping from comparatively shallow plateaux to great depths, by what is known to occur wherever great masses of sediment are found, and he therefore considered these plateaux to be submerged mountains. Such they undoubtedly are, in a certain sense; not wholly built, however, as Darwin supposes, of sediment, but in great part also of the remains of the innumerable animals living and dying upon them. The nucleus of these banks has probably been formed around the shores of promontories subjected to the most active play of the great oceanic currents.

At the time when Darwin wrote, and when we knew little of the limestone deposits formed by the accumulation of the *débris* of Mollusks, Echinoderms, Polyps, and the like, upon folds of the earth's crust, the basal parts of barrier reefs were difficult of explanation. The evidence gathered by Murray, Semper, and myself, partly in districts which Darwin had already examined, and partly in regions where his theory of reef formation never seemed to find its proper application, has in part removed this difficulty. It all tends to prove that we must look to many other causes than those of elevation and subsidence for a satisfactory explanation of coral reef formation. All important among these causes are the prevailing winds and currents, the latter charged with sediment which helps to build extensive plateaux from lower depths to levels at which corals can prosper. This explanation, tested as it has been by penetrating into the thickness of the beds underlying the coral reefs, seems a more natural one, for many of the phenomena at least, than that of the subsidence of the foundation to which the great vertical thickness of barrier reefs has been hitherto referred. It is, however, difficult to account for the great depth of some of the lagoons — forty fathoms — on any other theory than that of subsidence.

If, however, we have succeeded in showing that great submarine plateaux have gradually been built up in the Gulf of Mexico and the Caribbean by the decay of animal life, we shall find no difficulty in accounting for the formation of great piles of sediment on the floors of the Pacific and Indian Oceans, provided these banks lie in the track of a great oceanic current. Certainly the coral reefs of the Caribbean and the Gulf of Mexico, of Florida and the Bahamas, are distributed upon banks which lie directly in the path of the great Atlantic equatorial currents and of the Gulf Stream, which we know to have been formed by the agency of these currents. The fact that the coral reef at the extremity of Florida is the most recent of the coral formations found on the Florida shores, plainly shows that they, as well as the coral reefs of Yucatan, Cuba, the Bahamas, and the Caribbean Sea, though not all of the same age, were yet of modern origin, since we find them still in an active state of formation. Even the elevated reefs of Cuba and of the other West India Islands, though older, probably belong, nevertheless, to the most recent deposits of the kind we know. The difficulty of explaining the constant renewal of the coral faces of the atolls of the Pacific, and their present condition, on the supposition of their having lived from the time of the early Tertiaries, was one of the main causes which led Darwin to seek for some other agency, like subsidence, to explain the renovating process of the original structure. In some instances coral reefs have unquestionably been lifted. I have seen the elevated reefs of Cuba, of San Domingo, and other West India Islands, and especially of Barbados,[1] which are perhaps the most striking of these. They are too well known to need more than a passing notice here. The terraces they form show plainly the successive stages of arrest in the agency of elevation, and there is no difficulty in accounting for their existence, especially in a volcanic region like the West Indies; but that there should have been an extensive area of subsidence in which the rate of subsidence was so evenly balanced with the rate of coral growth as to create and maintain the necessary conditions for reef formation, is less easy of explanation.

In a very interesting article on the Bermudas, Rein[2] has taken very much the same view of their gradual building up, and explains the formation of the present condition of things by causes greatly differing from those adduced by Darwin as explaining the apparent atoll shape of the groups.

The islands composing the Tortugas (Plates I. and II.) are Loggerhead, Bird, Garden, Long, Sand, Middle, and East Keys. These are always above the level of the sea, while Southwest Key and Bush Key are only exposed at low water, and North Key and Northeast Key have disappeared. These insignificant islands are the outcrops of extensive submarine banks. Loggerhead Key, not more than three fourths of a mile in length, is the top of a bank extending to the three-fathom line of about five miles in length with an average width of three fourths of a mile, extensive coral sand-flats running in prolongation of the northern and southern extremities of the

---

[1] The trachytic cone forming the base upon which the successive terraces of Barbados have been elevated is seen to crop out on the surface in the northeastern part of the island.

[2] Rein, J. J. Beiträge zur Physikalischen Geographie der Bermuda Inseln. Bericht. Senckenb. Naturf. Gesell., 1869–70, (Mai 1870,) pp. 140–158.

key. This bank we have called in the sections (Plates III. and IV.) Loggerhead Bank. Between this and the Garden Key and Long Key Bank, there are a few shoals running more or less parallel with Loggerhead Bank, the largest of which are Brilliant and White Shoals. Garden Key and Long Key Bank form a rectangular shoal of nearly the same length as that of Loggerhead, with an average width of nearly two miles, the great sand flats of this shoal being those of the Long and Bush Key tract. The Southwest Channel, with a depth varying from ten to twelve fathoms, separates Loggerhead Bank from the Bird, Garden, and Long Key Bank. This, in its turn, is separated from the still greater North, Northeast, East, and Middle Key Bank by the Southeast Channel, with a depth of about nine fathoms, while the Northwest Channel separates Loggerhead Bank from the North Key Bank with an average depth of from seven to ten fathoms. The Eastern Bank is irregularly horseshoe-shaped, convex to the east, and partly surrounds a great interior bay, with an average depth of about seven fathoms. The flood tides run from the south through the Southwest and South Channels in a northeasterly direction, the ebb tide flowing in the opposite direction. The strongest tidal current passes through the Southwest Channel.

An examination of the sections of the Tortugas from the west to the east, on the lines parallel to *A A′*, *B B′*, etc. (Plate IV.), shows the gradual rise of the mound forming the Tortugas, as we pass from the west side of the Loggerhead Bank along the line *A A′* to a line passing through the southwest slope of the same bank, *B B′*, till we come across the main bank of the group on the line *C C′*, and again fall slowly on the eastern slope as we cut across the east end of East Key Bank on the line *D D′*, till we finally come to the low elevation forming the southeast slope of East Key Bank along the line *E E′*. The action of the Southeast and Northwest Channels in keeping open the passage between Long Key and Loggerhead Bank, and that between North Key Bank, is well shown on the sections *B B′* and *C C′*, as well as the secondary channels separating Bird Key, Garden Key, and Long Key. These channels are undoubtedly the last traces of the deeper and wider channels, probably once running parallel to the Southeast Channel. They have little by little been filled up after the sand flats of Bush Key began to form, thus preventing the free circulation of the tides through these channels. The presence of a few large heads of Mæandrinas and Astræans, as well as the luxuriant growth of *Madrepora cervicornis* near low-water mark, on the two sides of these channels, now changed into sand flats (see Plate II.), seems to indicate formerly a more active tidal circulation through them than is now taking place. An examination of the cross-sections in the direction of the prevailing winds, and in the direction of the tides along the lines 1–1′ to 10–10′

(Plate III.) shows at a glance the mound-shaped mass which forms the base, rising from the general twenty-five to thirty fathoms level, with its abrupt side facing the east on the extremities 1′–10′[1] of the section lines. There are also seen the deep furrows, more or less broad, which have been scooped out of this mass by the action of the currents, such as those passing through the Southwest Channel. (See lines 1–1′ to 6–6′, with the secondary channels cut between the Loggerhead Bank and the Brilliant and White Shoals, Bush, Garden, and Long Keys; lines 2–2′, 3–3′, 4–4′, 5–5′, as well as the primary channels formed by the Northwest Channel and the secondary between Middle and East Key, on line 7–7′ and 8–8′.) With this preliminary examination of the relief of the Tortugas, we can now pass to the examination of the distribution of the more important species of corals, and see how far we are able to explain the peculiar formation of the Tortugas from causes still in operation at the present day (Plate II.).

The corals which give to the reefs their peculiar physiognomy are the extensive patches of Madrepora (principally *M. cervicornis*), the clusters of the two common species of Porites (*P. furcata* and *P. clavaria*) more or less covering the shallow tracts of coarse sand, and *Mæandrina areolata* growing between the more or less extensive patches of marine lawns formed by a species of Thalassia, with occasional patches of Anadyomene. In other parts of the reefs large Holothurians (Mülleria) lie scattered on the bottom, or in somewhat deeper regions we find pockets filled with large Diadematidæ. Immense masses of Nullipores (*Udotea Halimedea*) and Corallines grow on the shallowest flats on the tops of the branches of Madrepores which have died from exposure to the air, either from growing up to the surface and becoming exposed by extreme low tides, or from the action of strong winds blowing the water from the flats. The destructive effect of an extremely low tide on a growing reef is well shown on the flats to the southward of Fort Jefferson, where the upper part of the branches of a certain size reaching up to a given level are frequently killed off by low tides. Exposure to the action of the sun even for a very short time is sufficient to kill them. The extreme sensitiveness of all corals to atmospheric action is well known, so that it becomes plain, as has been stated already by Darwin, Dana, and others, that no coral reef can grow above the level of the lowest tides, and that all subsequent additions of material must be due to accumulation of sediment transported by the action of the tides

---

[1] Loggerhead Bank itself also shows, as well as Garden, Bush Key Bank, and East Key Bank, a steep slope on the eastern face. Although an interior slope, it is yet sufficiently exposed to the same influences which have shaped the outer slopes of the more exposed banks.

and prevailing winds. Next come the clusters of coral heads, huge masses of Astræans and of Mæandrina, very limited in their distribution at the Tortugas, as well as the more or less extensive patches of *Madrepora palmata*, and finally what is known as broken ground, namely, the outer edge of the reef occupied mainly by clusters of Gorgoniæ, which also reach upward into the shallower region. Occasional patches may be seen also of Astræans, Madrepores, and other reef-builders, which have extended below the depths at which they generally flourish, and where they are soon killed or choked by the accumulation of fine coral sand, and coralline sand or ooze of the deeper waters. This sediment fills the broad and narrow flat channels dividing the three great banks which compose the Tortugas, or separate the inner shoals, banks, and islands. Finally come in the lines of broken coral heads and branches, mixed with dead corallines, shells of Mollusks, old Serpulæ tubes,[1] Gorgoniæ stalks, and the like. These form a low dike, as it were, to be little by little pounded up by the breakers into smaller fragments, and carried, either by the winds, or waves, or currents, into the interior of the reefs, there to form sand flats of more or less coarse materials, until on the western faces of the banks the finest detritus is deposited in very steep slopes, constantly shifting like those of sand dunes, and, like them, running forward and backward at the will of the winds and waves. This continues until the particles have become cemented together by the action of the carbonic acid contained in excess in the salt water surrounding the reefs, and the gluing of the slight amount of animal matter which holds these particles together. Some of the slopes (according to General Wright, of the Engineers) are as great as thirty-three degrees. All this fine material, composed of fragments of all sizes of every animal and plant with a calcareous skeleton, of course prevents the growth of corals in positions which are not well scoured, either by the action of the tides or of the prevailing winds. The corals when alive are gradually buried under this mass of material constantly passing over them, and held in suspense. They flourish therefore only where the disturbing elements are reduced to a minimum; namely, on steep banks or on the slopes which are scoured by tides, or on flats at considerable depths, over which a large body of water can freely pass, whether brought by the tides or driven by the winds. In such cases the corals can grow gradually towards the surface as fast as the sediment deposited has closed up the circulation of the lower levels. The quantity of calcareous matter held in suspense in the water in the vicinity of a reef, and on the reef itself, is very great. The breakers pounding

---

[1] Serpulæ often form incrusting masses of considerable extent, acting, as has been noticed by Darwin, much as the patches of Nullipores do in protecting decayed and dead corals from being too rapidly broken to pieces by the action of the waves.

upon the exposed slopes of the reefs destroy, even on calm days, large quantities of corals which have been weakened by the borings of Mollusks, Annelids, Echinoderms, and Sponges. On windy or stormy days the powdered fragments are driven far and wide, turning all the surrounding water to chalk color for a considerable distance from the reef. It is not an uncommon thing after a blow to come upon this water discolored by the fine calcareous silt it holds in suspense to a distance of six to ten miles from the outer reef. I have seen between two and three inches of fine silt deposited in the interval between two tides after a prolonged storm. The limitation of coral reef growth to shallow depths may be due to the fact that the ooze held in suspense rapidly sinks to the bottom from the top, the surface water remaining clear. The rapidity with which the corals are choked readily explains why they must of necessity have a limited vertical distribution depending upon local causes. This is well shown along the sections of Tortugas off the Marquesas, along the line of the main reef. We find corals living and flourishing at a much greater depth, and there seems to be no simpler explanation of the limited bathymetrical range than that of the baneful action of the silt held in suspense near all reefs. That the silt is carried on the bottom by currents and waves is well known, and on the bottom of the Gulf Stream to the north of the Straits of Bemini as far as Cape Hatteras, we have a huge muddy river carrying its silt to the steep slope south of Hatteras, depositing occasionally a few patches of green sand along the sides of its course, while the upper waters are perfectly clear and of the deepest blue.

Corals alone cannot supply all the sand we know to be carried by the Gulf Stream. We must add to this the silt, mud, and sand which comes from pelagic animals, and which is distributed by the winds and waves, to be spread uniformly over large areas, as is well shown from the distribution of the immense mass of calcareous ooze over the whole of the bottom between Florida and Cuba. This undoubtedly owes its origin in part to the silt the Gulf Stream brings from the southeastern edge and slope of the Yucatan Bank, in addition to the accumulation due to the pelagic fauna which it sweeps along its course. The amount of work done by the animals living upon the reef in preparation for the grinding process of the breakers is very great. All writers upon the reefs have referred to the destructive agency of boring Mollusks, Annelids, and Echinoderms riddling the coral branches and heads with holes, and preparing the way for their fracture into larger or smaller fragments.

The Echinoderms living upon the flats seem to live almost exclusively upon the organic matter and Foraminifera they find mixed with the coral sand, upon which they feed and which fills their digestive cavity. Their action, however, while undoubtedly an important one in that they reduce the sand to a smaller size, is yet very slight as compared to the action of the breakers upon the sea face of the reef. Darwin, Dana, and others have referred to this agency as one among those at work in triturating the corals. By some observers, these animals are supposed to be simply on the living coral. This is certainly not the case either with Holothurians and Diadematidæ, or with Clypeasteroids: livingon flats, they swallow the sand as they find it. But with Cidaris and Echinometra, which dig out holes in the rock, the case is different. H. H. Guppy has also observed the Holothurians full of sand on the flats of the reefs of the Solomon Islands.

The Loggerhead, Bird, and Bush Keys Banks, which protect each other to a certain extent from the action of the strong winds opposed to the prevailing trade winds, present a more normal growth than that of the East, North Key Bank, which is particularly exposed to the full fury of the northers, which must counteract to a great extent the action of the trade winds. This can be seen on sections (Plate III.) 7–7′, 8–8′, 9–9′, which show a nearly equal slope on the eastern and western sides of the bank. The distribution of the broken ground, the position of the masses of *Madrepora cervicornis*, and the trend of the sand flats, all alike show the conflicting action to which the two slopes of this great bank have been subjected. This counterbalancing action of the northers and of the trade winds is also well shown by its effect on the position of the islands themselves. During the prevalence of southeasterly winds, East Key, Sand Key, and Middle Key extend bodily to the westward, the materials for their growth being washed from the eastern shores. The opposite takes place during the prevalence of northers. The outline of Loggerhead Key is also constantly shifting, and, according to the officers of the Lighthouse Board, none of the landmarks furnished by these islands can be relied upon in the location of buoys.

What takes place upon the shores of the islands also takes place, of course, upon the flats. Owing to the action of the winds and waves, the whole mass of the surface of the reef is kept in more or less active movement, according to the depth of the flats and to their position. The coarser materials covering the flats and shore lines, made up of large-sized fragments, are gradually changing to the coarse sand forming the flats nearer the outer edge of the reefs; and these, in their turn, are changed into the fine silt which fills the channels and eventually limits the growth of the corals to regions where they can find permanent lodging, and are not immediately under the influence of this shifting sand and silt. The quality of the sand forming the beaches at different points on the keys and flats depends entirely on its position. It will be coarser or finer, according to the exposure of the beach, and the finest sand is found in the most sheltered places, where the silt has free chance to settle. (See Plate IX. for a view of a characteristic coral sand-beach at Key West.) The scarcity of fossils in the coral limestones of the reef has already been dwelt upon, and their absence is readily accounted for from the constant disturbance of the shore-line deposits, reducing little by little the larger fragments of shells and corals, or Echinoderms, to a breccia, or again to oölite or fine sand. This is nowhere as well seen as on the shore line of Key West to the north of Fort Taylor (Plate XII.). There the outer reef is sufficiently distant to allow waves of considerable size to break upon this coast, and then strike upon a low line of shore rocks. These rocks are completely riddled by larger or smaller cavities made by boring Mollusks, Annelids, Sea-urchins, etc., or left by fossils or fragments of corals which have fallen out. Thus weakened, large masses are easily undermined by the water, which washes around them with considerable force. They fall off, become then broken again into smaller and finer pieces, which are again reground in their turn, and are finally either resoldered into finer breccia or coarse oölite, according to the composition of the rock, or into the finest oölite or sand. This is then cemented again to the shore line, forming a new line, more or less regularly stratified, dipping towards the sea, and which, when exposed to the action of the air, soon becomes coated with a thin film of hard limestone. This hardens, and forms the ringing crust of the rocks found everywhere on the keys. This coating is formed with great rapidity, an exposure between two tides is sufficient to form such a thin coating, as I have repeatedly had occasion to observe in the deposition of finer oölitic sands which fill the rock pockets just within reach of the waves at high tide. A process of undermining similar to what has been observed at Key West takes place along all the coral rock shores which happen to be exposed to the action of the sea. From the description of Rein and others, this undermining action, acting on a very much larger scale on æolian deposits of considerable altitudes, must be the principal agent in the formation of some of the peculiarly characteristic features of the Bermuda Islands. On the east and west shore of Loggerhead, near the northern extremity, we can trace admirably the successive layers of the coral limestone which have been deposited and have had an opportunity to harden between the tides, forming what appear to be stratified beds, with their outcrops running as a general thing parallel to the bend of the shore or at a slight angle from it, and dipping on the one side to the eastward and on the other to the westward.

The bank to the west of the Tortugas has large heads of Astræans and Madrepores growing up in it at a depth of from six to seven fathoms. Gorgoniæ are still found at a somewhat greater depth. This bank is an excellent specimen of an isolated coral patch, such as must have formed the basis of all the keys and reefs. This patch will undoubtedly in time form a new reef flush with the surface to the westward of the Tortugas. The greatest depth at which reef-building corals were observed to grow was in the Southwest Channel on the steep banks of White Shoal, and in the channel to the southwest of Bird Key, where Madrepores grow to a depth of about ten fathoms. As a general rule, however, the corals were generally choked below six fathoms by the ooze, and their place was taken by Gorgoniæ.

All estimates of the age of the southern extremity of Florida, or of the reef alone, must necessarily be very defective. The great age assigned by Professor Agassiz to the northern part of the peninsula may not be exaggerated, if it is understood as including the time at which the Vicksburg limestone forming its backbone was deposited. But the extension of the coral reefs proper so far north in Florida has never been proved. The rate of growth of the reef-builders is very rapid, and it is quite possible that the reef-builders of the Florida Reef began at once all along the line extending from Key West to Cape Florida, and quickly reached the surface, forming at first a barrier somewhat less compact than the present line of reef. Uncertain as we are respecting the time at which the various parts of the reef reached the surface, one can only say that in Florida, limiting the estimate strictly to the depth at which corals grow, it would probably take one thousand to twelve hundred years for corals to rise from the seven-fathom line to the surface. This would give us no clue whatever to the actual age of the reef, because it is difficult to determine how far the width of any coral reef is due to the growth of coral. But supposing the reef to have an average width of half a mile, and their lateral growth to be say four or five times more rapid than their vertical increase, we should get at least twenty thousand years as the age of the outer reef. It is quite possible for a great width of reef to be forming at one time, and to spread laterally with great rapidity if the plateau upon which it grows is of the right depth. Take, for instance, the width of flats upon which Madrepores flourish. A plateau at favorable depth would very soon be covered by them; they would spread rapidly until they reached the edge beyond which no corals could thrive on account of the depth.

Thus we see from the sections and a study of the distribution of the corals, that at the present day material is constantly added to the knoll forming the Tortugas; that this material is derived either from the animals and plants living upon the reef, or from the pelagic animals which die while passing through the channels, and that we can find nowhere any trace of elevation. Here the calcareous material has evidently been heaped up to its highest point by the influence of the waves or winds. Furthermore, we see growing to the westward of the Tortugas a knoll similar to that which has formed the Tortugas themselves, and which will form, in the course of time, an island or a series of islands like them, to the westward. It is further evident, also, that the great Alacran Reef (Plate V.) has been built up in a similar way, and that its peculiar atoll shape is entirely due to the action of the prevailing winds and currents, and not to any subsidence of the great Yucatan Plateau.

The character of the Fauna and Flora of the Tortugas is interesting as corroborating the comparatively recent age at which the reef has been formed. We find, as we go north along the keys, that the nearer we come to the mainland of Florida, the greater do we find the number of plants characteristic of the mainland. As we reach islands more or less inaccessible, or islands merely formed by flats which have reached low-water mark, we find the vegetation to consist almost entirely of mangroves. Yet at the Tortugas, in spite of the narrow channel which separates them from the Marquesas, I saw but a single diminutive mangrove plant, while a few Bay-cedars, as they are called, a Hop-vine with a thick white flower, and Bermuda grass, have alone found their way there, in spite of the fact that the Tortugas are in the direct line of the prevailing winds from the Marquesas. One of the species of land shells common at Key West has already found its way to the Tortugas. The group is visited by pelicans, cranes, humming-birds, plovers, and a few land birds. It being the winter season, the insects were few in number. No terrestrial reptiles have as yet been found on the Tortugas, while at Key West we find many of the frogs, toads, lizards, and snakes characteristic of the southern spit of the mainland, all this showing that the Tortugas reefs have not been above the level of the sea long enough to have received as yet the fauna or flora characteristic of the more northern line of keys.

The explanation given in this paper of the formation of huge deposits of limestone from the limestone carcasses of Invertebrates, takes it for granted that the most favorable conditions for their support exist, and this condition we assume to be an abundance of food brought to them by the great oceanic currents passing over the regions where these submarine plateaux are forming. We know as yet too little of the fauna of the oceanic basins to be able to affirm how far the population of the bottom depends upon the food it receives from oceanic currents. We can only judge by analogy. No marine fauna has as yet been explored which equals in variety or in the number of its individuals that of the Caribbean and of the Gulf of Mexico from the depth of two hundred and fifty to about one thousand fathoms. It has proved richest in the districts most favorably situated with regard to the currents and the food supply they bring in their track. It is but natural to extend this effect to other great oceanic currents, and in their track we may therefore expect to find the most favorable conditions for the support of an immense fauna. In fact, the question of food is of the utmost importance to the distribution, not only of marine, but of terrestrial animals, and the absence or presence of an abundant supply of suitable nourishment must of necessity be an all-important factor in the character and variety of the fauna of any place or period, — far more influential, perhaps, than the many obscure physical causes upon which we are so apt to explain the distribution of animal life. On the continental ledges, where the shore detritus is gradually accumulated, bringing with it a large amount of animal and vegetable food, we find the most populous fauna near the hundred-fathom line. When, in addition to the action of the influences which have accumulated the shore detritus, we have a continental shore or plateau bathed by a great and powerful current, bringing with it an abundance of pelagic life, we may expect a superabundant supply of food, and consequently a fauna of unusual richness and variety. The fauna of the Pourtalès Plateau, of the hundred-fathom slope to the westward of the Tortugas, of the northeastern slope of the Yucatan Plateau, of the windward side of the Lesser Antilles, and of the continental slope of the eastern coast of the United States below the hundred-fathom line, are all examples of such districts supporting a marine fauna of surpassing richness. In a similar way, we may expect to find in the track of the great Pacific equatorial current also the most favorable conditions for the support of a rich and varied marine fauna. The "Challenger" found, perhaps, no richer field than that off the coast of Japan, which lies directly in the track of the Japanese current, and may be considered as the Pacific counterpart of the Florida and Caribbean fauna.

In past geological times the effect of the currents in determining the distribution of the marine invertebrates must have been as marked as it is at the present day. As long as we had a great equatorial current running practically unbroken round the world, and only slightly deflected by the great continental islands of Central America and of the East Indies, which stood in the path of this great equatorial belt, it was natural that we should have a very extensive geographical range for all the tropical marine forms. It was only after the complete shutting off or comparative isolation of the Atlantic from the Pacific that different physical conditions began to exist simultaneously, which were of the greatest importance in reducing the supply of food to the animals on the west coast of the continental barriers, and in extending towards the north, as far as the temperature would allow, a supply of food far more abundant than that with which the fauna of the eastern coast was supplied before such a break of continuity existed. As this separation of the Atlantic and Pacific probably took place late in the Cretaceous period, and was perhaps not completed till the Middle Tertiary, we shall naturally expect to find the marine fauna of the earlier geological periods of the Old and the New World to be very similar, and consisting of many identical species. These older faunæ flourished on the shores and continental shelves, either washed by the great equatorial currents or by branches extending both north and south along the then existing continents and continental islands; and where we now find rich fossiliferous deposits we may feel assured that the beds at the time of their formation lay in the track of a primary or a secondary marine current, which supplied an abundance of pelagic food indirectly necessary for the support of any rich marine fauna.

EXPLANATION OF THE PLATES.

PLATE I.

Sketch map of the Tortugas, showing the position of the reefs on the southeast extremity of the great Florida Plateau, and the commencement of the New Tortugas Reef to the westward of the Loggerhead Key. Reduced from Coast Survey charts.

PLATE II.

Colored map showing the distribution of the principal types of reef-builders, as well as the distribution of coral sand and ooze. The hydrography of this map is taken from Coast Survey Chart No. 471^{a}; the original of this plate was colored on the spot.

PLATE III.

Sections across the Tortugas, prepared from Coast Survey Chart No. 471^{a}, along the lines marked 1–1′ to 10–10′ on Plate II. 6 fms. = $\frac{1}{3}''$.

PLATE IV.

Sections across the Tortugas, prepared from Coast Survey Chart No. 471^{a}, along the lines marked *A–A′* to *E–E′* on Plate II. 6 fms. = $\frac{1}{3}''$.

PLATE V.

Sketch map of the Marquesas. An atoll to the westward of Key West along the continuation of the line of keys, with section along the line *A B*, prepared from Coast Survey Chart No. 470. Vertical scale, $\frac{1}{8}'' = 1$ fm.

Sketch map of the great atoll of Alacran Reef, on the Yucatan Bank, with a section prepared from the Hydrographic Office Chart No. 403. Vertical scale, $\frac{1}{4}'' = 5$ fms.

PLATE VI.

Sketch map of the southern extremity of Florida, to show the lines along which the sections Cape Romano–*G′*, *S–G*, *T–S*, *M*-Cape Sable, *M–F* of Plate VII., and the lines Mainland to 1, 2, 3, 4, 5, 6, 7, 8, 9–9 to 13–13, as well as the line along the course of the reef of Plate VIII., have been taken. Prepared from Coast Survey charts.

PLATE VII.

Sketch map of Florida, showing the lines along which the sections of this plate have been prepared. See also Plate VI. for some of the lines extending partially across the reef. Constructed from Coast Survey charts.

PLATE VIII.

Longitudinal section along the course of the reef from off the Quicksands to off Cape Florida. Cross-sections of the reef along the lines 1–13 of the sketch map of Plate VI. Constructed from Coast Survey charts.

PLATE IX.

Coral sand beach south of the Navy Depot, Key West.

PLATE X.

Mangrove Islands in the distance, seen from the mangrove beach north of the slaughter-house, Key West.

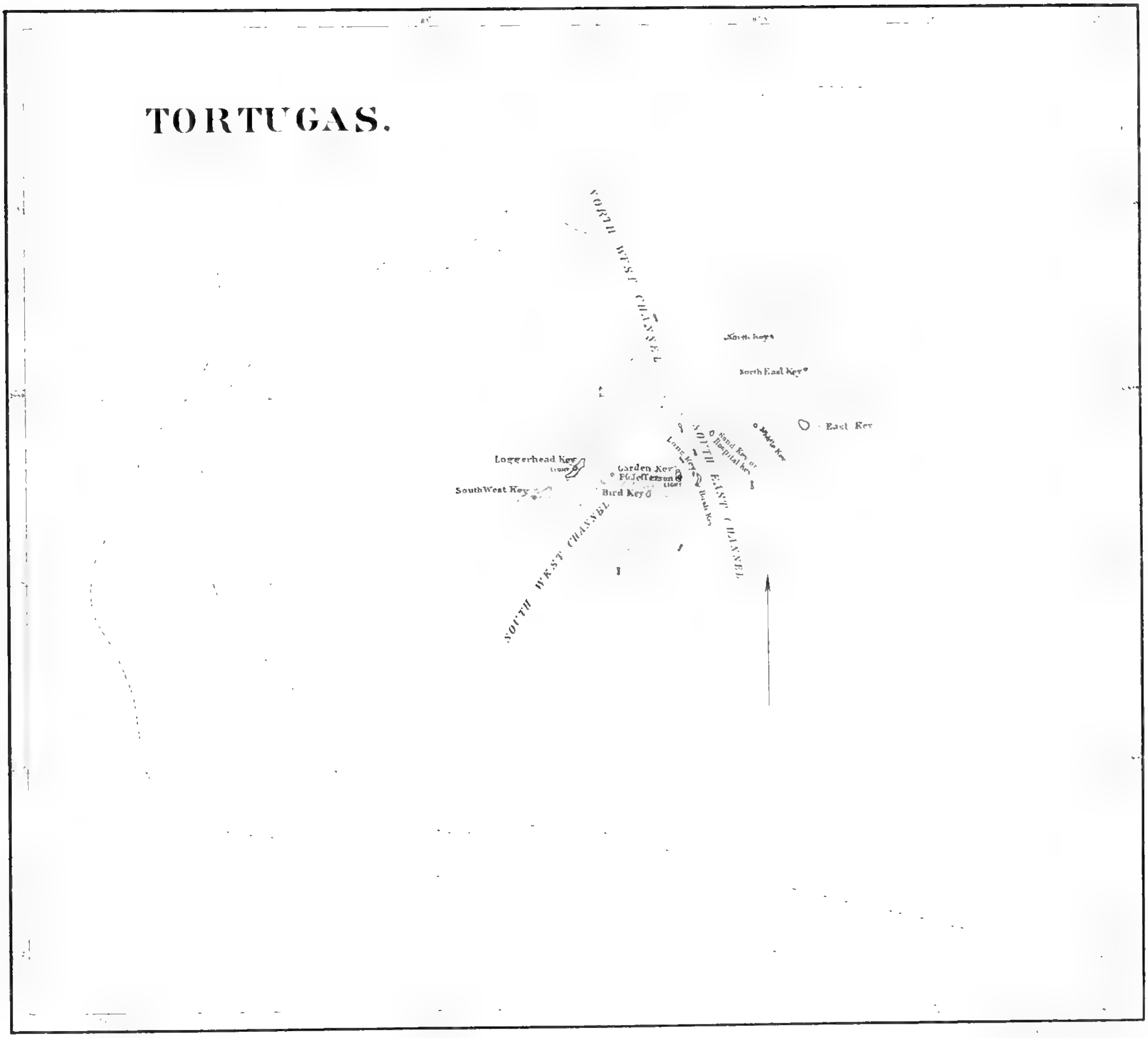
PLATE XI.

Lagoon formed by promontories and low islands covered with mangroves, on the northeast shore of Key West, near the slaughter-house.

PLATE XII.

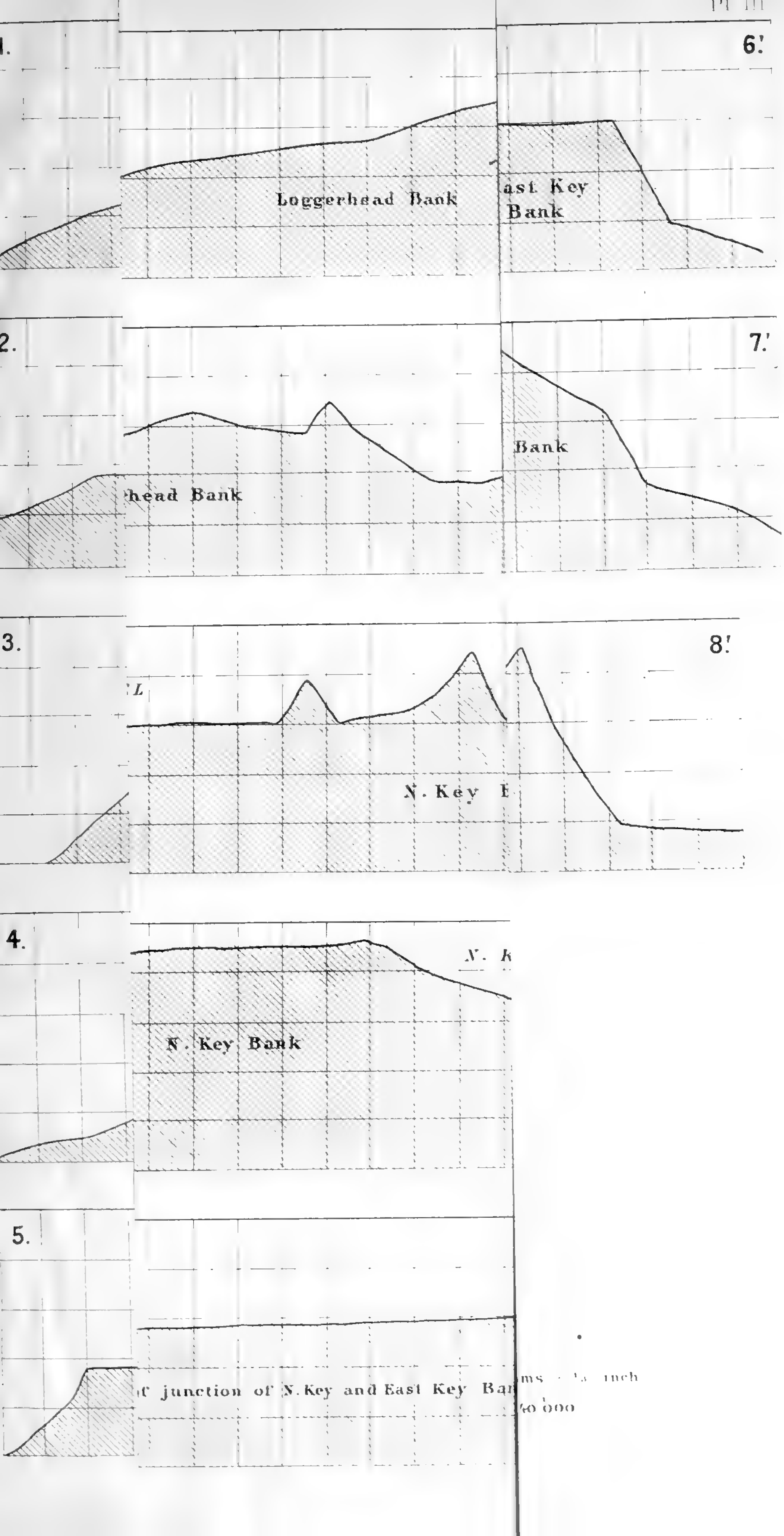
Coral-rock beach north of Fort Taylor, exposed to the action of the waves of the channel between the outer reef and Key West.

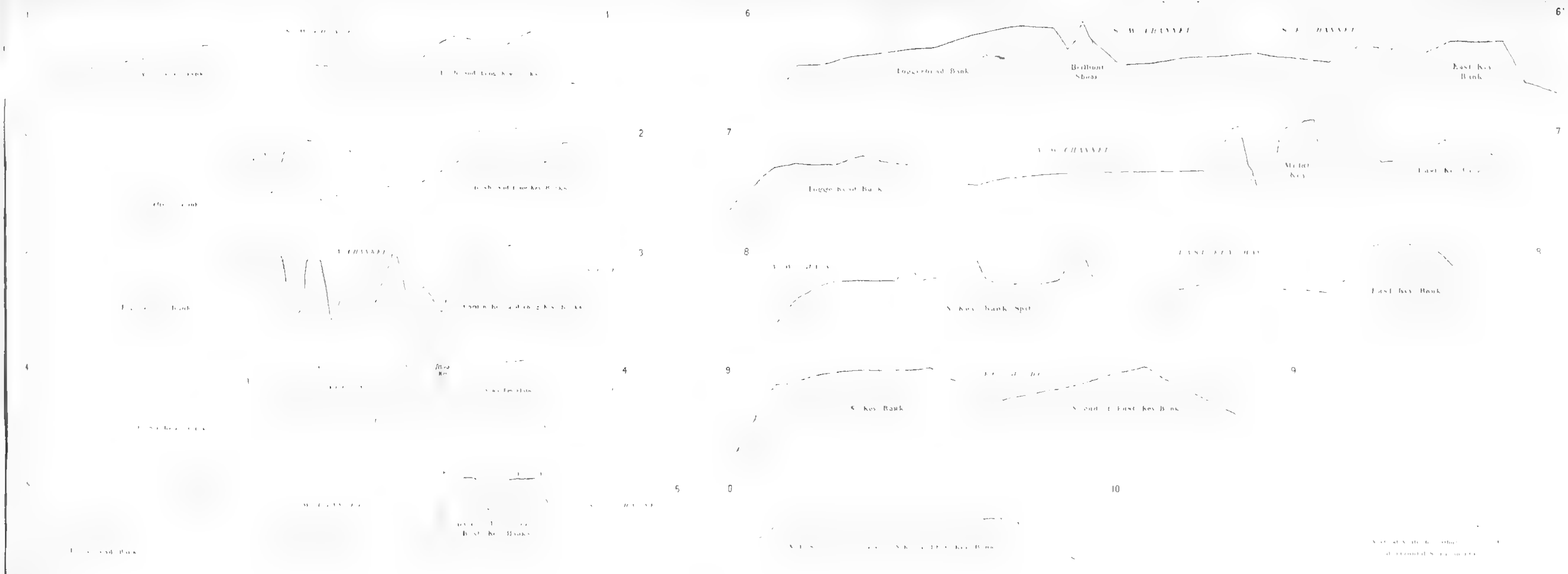
TORTUGAS.


NORTH WEST CHANNEL
North Keys
North East Key
East Key
Middle Key
Sand Key or Hospital Key
Long Key
SOUTH EAST CHANNEL
Loggerhead Key
LIGHT
Garden Key
Ft Jefferson
LIGHT
South West Key
Bird Key
Bush Key
SOUTH WEST CHANNEL


TORTUGAS

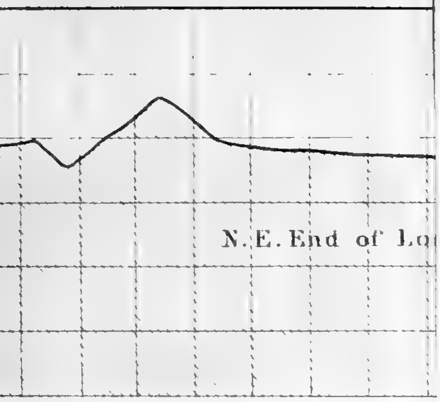
Scale 1/60 000

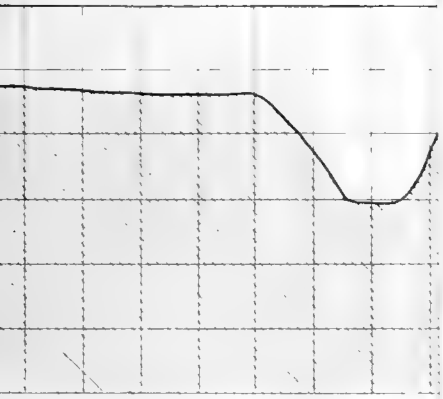

1.
6.
Loggerhead Bank
ast Key
Bank
2.
7.
head Bank
Bank
3.
8.
L
N. Key B
4.
N. K
N. Key Bank
5.
f junction of N. Key and East Key Ba
ms = ½ inch
60 000

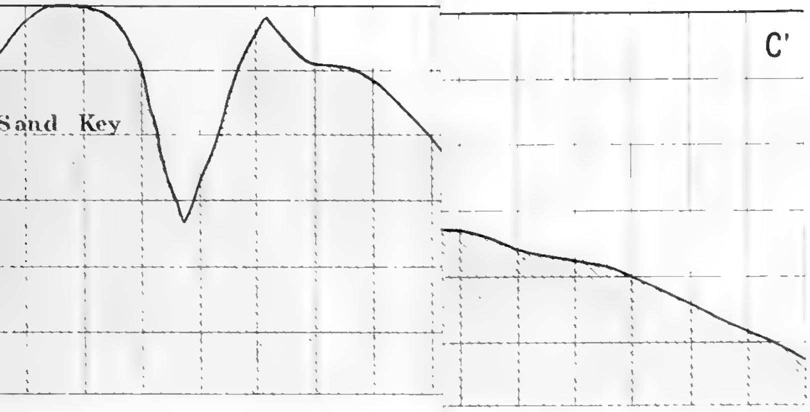

1
2
3
4
5
6
S. W. CHANNEL
S. E. CHANNEL
Loggerhead Bank
Brilliant Shoal
East Key Bank
6'
7
S. W. CHANNEL
Loggerhead Bank
Middle Key
East Key
7
8
East Key Bank
S. Key Bank Spit
8
9
S. Key Bank
S. end of East Key Bank
9
0
10

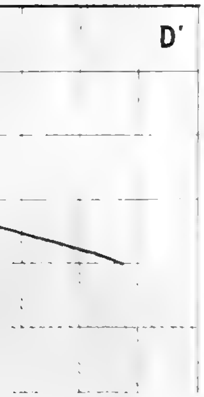
Pl. IV

Pl. V.









ale 6 fathoms = 1/3 inch

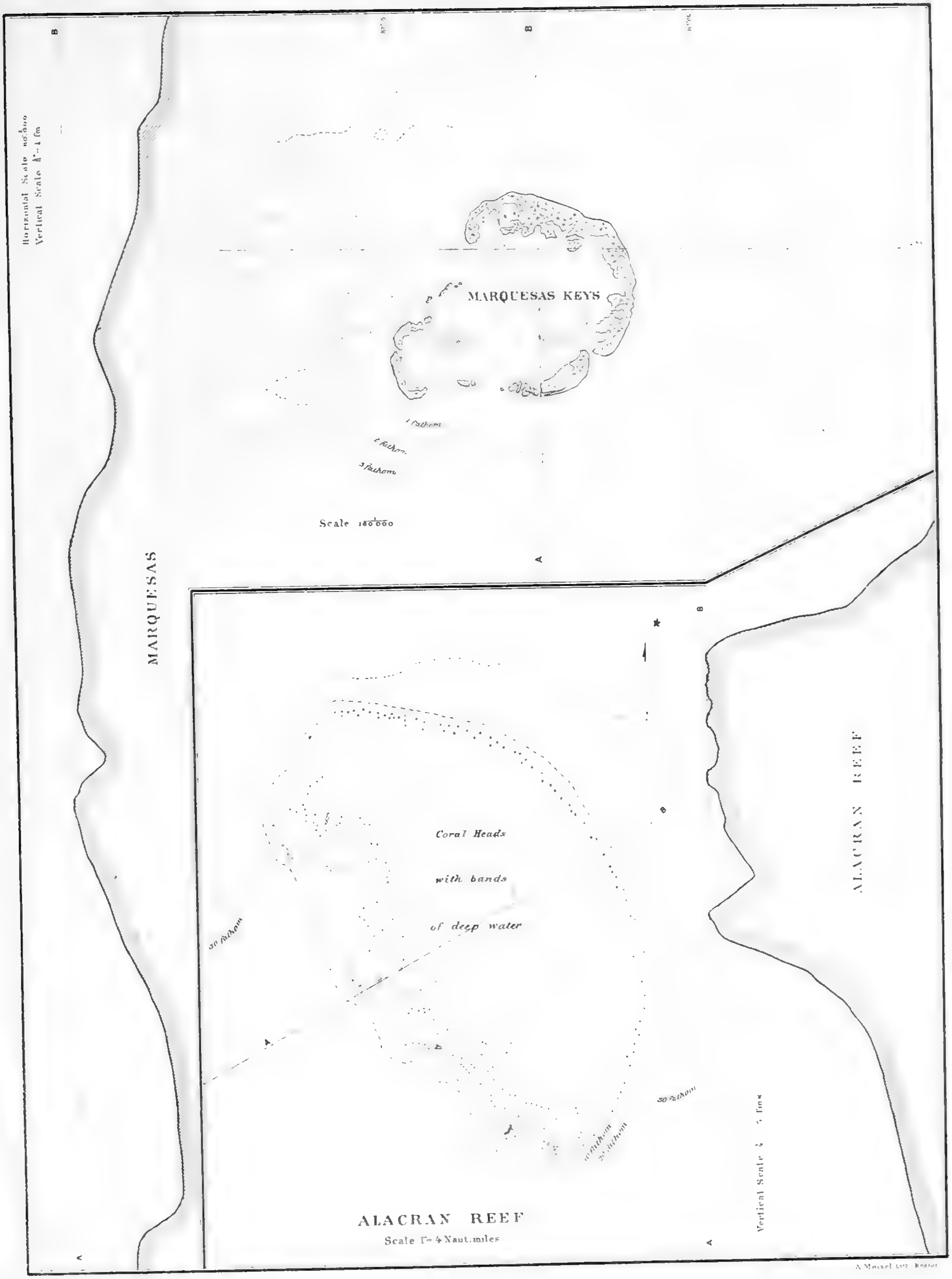
ontal Scale 1/40 000.

A. Meisel Lith. Boston

Lith. Boston

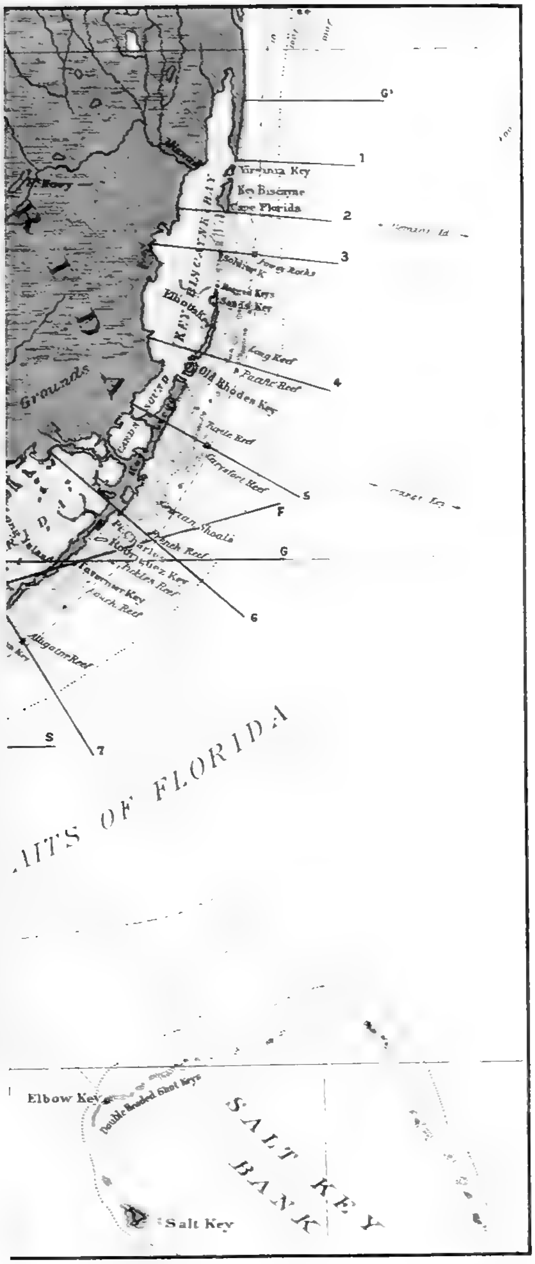

A
B
CHANNEL
C
D
D
E
E

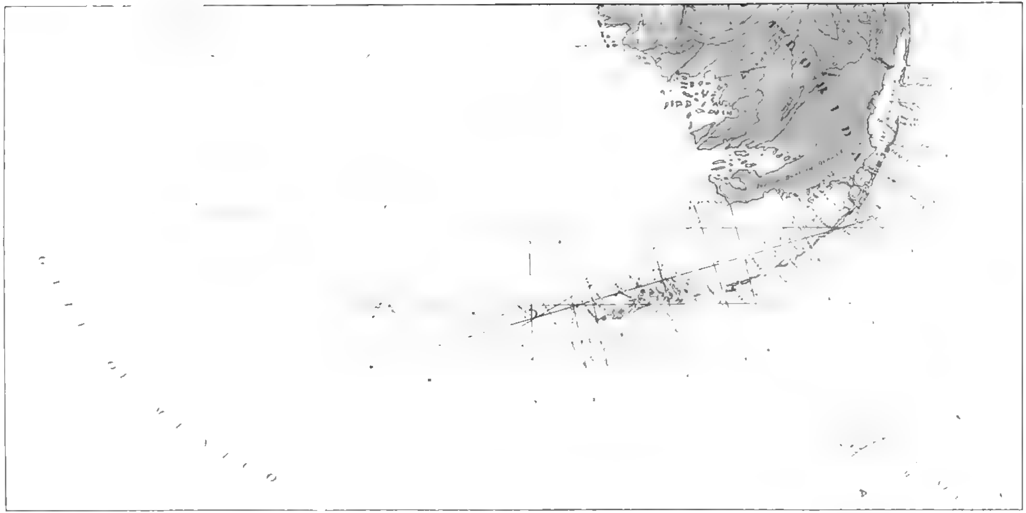
Pl.V.



A. Meisel Lith. Boston

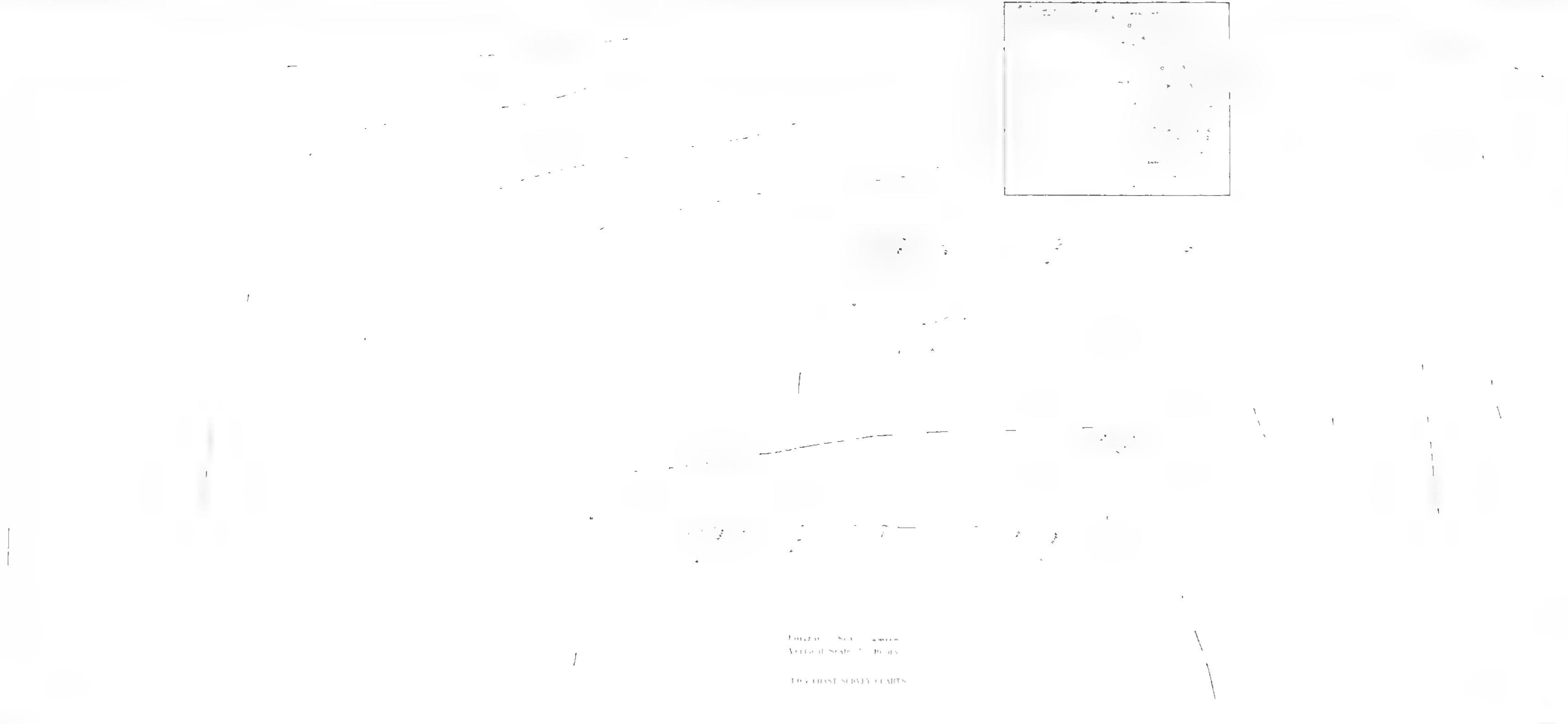
Pl. VI


G'
1
Virginia Key
Key Biscayne
Cape Florida
2
3
Soldier K.
Fowey Rocks
Ragged Keys
Sands Key
Elliott Key
BISCAYNE BAY
KEY
Long Reef
4
Pacific Reef
Old Rhodes Key
Turtle Reef
Carysfort Reef
5
Grounds
F
G
Ft. Charles
Rodriguez Key
Pickles Reef
Tavernier Key
Conch Reef
French Reef
6
Alligator Reef
S
7
AITS OF FLORIDA
Elbow Key
Double Headed Shot Keys
SALT KEY BANK
Salt Key

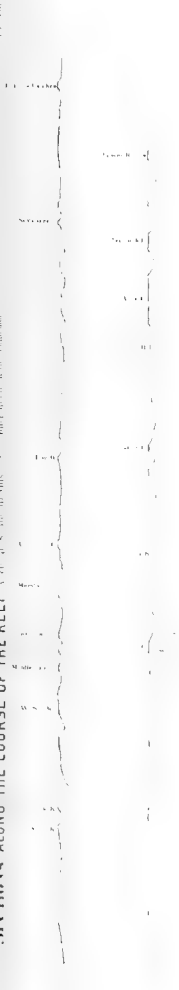


[illegible] OF FLORIDA

[illegible]



U.S. COAST SURVEY CHARTS



SECTIONS ALONG THE COURSE OF THE REEF

SECTIONS
ACROSS THE REEF

See Plate VI

MEMOIRS

OF

THE AMERICAN ACADEMY

OF

ARTS AND SCIENCES.

MDCCLXXX.

CENTENNIAL VOLUME.

VOL. XI.—PART III.—NOS. II., III.

CAMBRIDGE:
JOHN WILSON AND SON.
University Press.
1885.

II.

The Apparent Position of the Zodiacal Light.

By ARTHUR SEARLE.

Presented October 14, 1885.

In all the explanations of the zodiacal light which have at present any claim to serious consideration, it is assumed that the light is due to finely divided matter of some kind, illuminated either by direct sunlight or by the result of electrical or chemical action. This matter may be only a portion of the atmosphere, or of some cosmical mass more or less homogeneous. But in this case the illumination is presumed to be confined within certain limits. The object, therefore, which observers of the zodiacal light have ordinarily proposed to themselves has been the discovery of the position and extent of the matter thus illuminated. Its apparent position in the sky was accordingly first to be determined at particular times, and large numbers of sketches, representing its visible limits, have been made for this purpose, especially within the last fifty years.

In a previous communication[1] I have attempted to derive, from the published work of the chief observers of the zodiacal light, some conclusions likely to be of service in planning future observations, rather than in determining the apparent position of the zodiacal light from those already made. The prominent result to be obtained from the comparison of sketches of the zodiacal light had always been an uncertainty whether the outlines depicted by the observers afforded any distinct information with regard to the real object to be observed. As is remarked by Schmidt,[2] all the observations accumulated in the twelve years preceding 1868 seemed to add nothing to our knowledge with regard to the constitution and position of the zodiacal light. On this account, Schmidt recommends closer attention to the faint light sometimes seen in opposition to the Sun, and apparently due to causes of the same kind with those by which the zodiacal light itself is produced.

[1] Proc. Am. Acad. XIX. 146.

[2] Astronomische Nachrichten, LXXII. 342.

The first definite discovery tending to account for the perplexing discordances above mentioned, in the results of observation, was made by Jones,[1] who found that the apparent position of the light varied, in general, with the inclination of the ecliptic to the horizon. In the article already mentioned, I stated, as the apparent result of the data there collected, that this law is confirmed by the experience of other observers as well as by that of Jones, and that it should be referred to the effect of atmospheric absorption, as has been suggested by Geelmuyden. A further inference is that the method of observation by drawing outlines, as heretofore practised, is insufficient, and that it must be replaced by photometric observation of some sort.

It may be practicable, however, to obtain from the older observations some suggestion with regard to the apparent position of the zodiacal light, after correcting them roughly for the presumed effect of atmospheric absorption. Any suggestion thus attainable will lend additional interest to the work of future observers, although it can have no great importance of its own. In undertaking the inquiry, we shall be obliged to limit ourselves to the comparison of observations made by the same observer, since we already know that different observers form very different conceptions with regard to the outlines of the zodiacal light. It will also be desirable to compare observations made at the same elongation from the Sun, but at points differing considerably in altitude while they differ little in longitude. We likewise require observations made in as many different parts of the zodiac as possible. No published observations except those of Jones fulfil these conditions even approximately, and the inquiry here undertaken is therefore limited to the work of that observer.

The selection of observations for discussion was determined by the joint consideration of the time required by the reductions and the probable interest of the results to be derived from them. Upon the whole, it seemed best to employ all observations of what was called by Jones the "Stronger Light," made either in the evening or in the morning at the elongation 60°, and to omit the remainder. The limits of the light at this elongation are given for the evening observations in my former communication, Table X.[2] In collecting and reducing them for the present purpose, the following corrections were noticed to be required by that table. Under the date of Nov. 4, 1853, column "Elongation of Vertex," for the "Stronger Light," the figures 79, 82, 94, should be 80, 85, 96; for the "Diffuse Light," 106, 110, 114, 120 should be 109, 113, 117, 124; the data for

---

[1] Observations on the Zodiacal Light, Introduction, p. xvi.

[2] Proc. Am. Acad. XIX. 183–191.

the latitude of the boundaries of the "Stronger Light" at the elongation 60° should be omitted, as not determinable from the sketch. Under the date of July 15, 1854, the last result for the latitude of the boundaries of the "Stronger Light" at 60° should also be omitted. Under the date of Aug. 17, 1854, column "*t*," the last result, 18, should be 13.

The required data for the morning observations of Jones at the elongation 60° were obtained from his work by the method previously employed;[1] but the longitude of the sun was referred to a date one day earlier than that given by Jones, who employs civil time, so that the same longitude might be retained for all observations belonging to the same night, whether made early or late. This precaution, however, is of no practical importance, and might have been neglected without noticeably affecting the results, since a single degree is a relatively small quantity in the data here collected, and given below in Table I., the headings of which have the same meaning as those corresponding to them in Table X., already mentioned. An additional column in the present table gives the excess of absorption at the southern over that at the northern boundary, computed in terms of stellar magnitude by means of an auxiliary chart and the tables given in my former communication. As previously, negative quantities are indicated by Italic figures.

TABLE I.

Morning Observations by Jones: Stronger Light: Elongation 60°.

No. of Chart.	Date. 1853.	Long. of Sun.	Lat. of Obs.	*t*.	Lat of Bound.		Diff. Absorption.	No. of Chart.	Date. 1853.	Long. of Sun.	Lat. of Obs.	*t*.	Lat. of Bound.		Diff. Absorption.
					N.	S.							N.	S.	
		°	°	°	°	°				°	°	°	°	°	
13	June 15	83	26.2	38	4	6	0.29	53	Sept. 12	168	23.0	141	9	10	0.05
30	July 9	106	35.2	62	7	6	0.22					147	5	5	0.01
33	July 11	108	35.2	57	13	9	0.51	55	Sept. 14	171	23.0	121	8	6	0.13
35	July 13	110	35.2	59	10	7	0.40					128	8	6	0.05
37	July 15	112	35.4	53	10	9	0.87					143	6	9	0.02
				68	5	3	0.09	56	Sept. 15	172	23.0	133	4	6	0.02
38	July 16	113	35.4	54	10	5	0.45					144	6	6	0.02
39	July 18	115	33.7	56	9	8	0.73					149	3	2	0.00
				71	11	6	0.21	60	Sept. 30	186	22.4	144	7	5	0.03
40	July 19	116	32.1	72	7	0	0.07	62	Oct. 1	187	22.4	144	6	4	0.03
42	Aug. 5	132	21.5	103	5	10	0.06					152	6	5	0.02
43	Aug. 16	143	23.0	114	6	9	0.05					159	5	2	0.01
49	Sept. 2	158	23.0	111	8	8	0.13	64	Oct. 3	189	22.4	146	7	5	0.00
				124	10	8	0.04					161	6	5	0.00
50	Sept. 3	159	23.0	117	10	7	0.07	66	Oct. 4	190	22.4	147	7	5	0.00
				125	6	7	0.04					162	5	7	0.01

---

[1] Proc. Am. Acad. XIX. 171.

No. of Chart.	Date. 1853–1854.	Long. of Sun.	Lat. of Obs.	*t*.	Lat. of Bound.		Diff. Absorption.	No. of Chart.	Date. 1854.	Long of Sun.	Lat. of Obs.	*t*.	Lat. of Bound.		Diff. Absorption.
					N.	S.							N.	S.	
		°	°	°	°	°				°	°	°	°	°	
67	Oct. 8	194	22.2	151	9	5	0.00	177	July 7	104	28.9	58	12	11	0.42
				166	5	8	0.01					64	12	9	0.25
77	Oct. 31	217	22.4	174	5	5	0.00	178	July 8	105	29.2	61	13	9	0.29
79	Nov. 1	218	22.4	175	4	3	0.00					70	10	7	0.14
				190	5	1	0.00	187	July 24	121	25.6	66	12	9	0.48
81	Nov. 2	219	22.4	191	5	4	0.00					85	11	6	0.10
85	Nov. 8	225	22.4	182	11	6	0.00	189	July 25	122	25.6	65	12	6	0.45
				197	7	6	0.00					80	10	6	0.12
90	Dec. 29	276	22.3	240	7	7	0.07	191	July 26	123	24.4	79	12	9	0.22
				247	12	7	0.13	192	July 29	126	20.7	67	13	9	0.72
				262	6	7	0.05					82	13	9	0.20
92	Dec. 30	277	22.3	256	10	6	0.08					97	11	6	0.07
				268	10	7	0.06	193	July 31	127	19.5	83	12	10	0.20
94	Dec. 31	279	22.3	249	14	5	0.10					98	12	10	0.07
				264	13	8	0.08	194	Aug. 1	128	18.6	88	15	11	0.17
				269	14	8	0.08					99	13	10	0.06
97	Jan. 3	282	22.3	245	12	7	0.12	195	Aug. 4	131	17.8	98	14	9	0.07
				260	13	8	0.09	199	Aug. 21	148	14.5	108	11	10	0.04
99	Jan. 4	283	22.3	253	16	6	0.12	201	Aug. 22	149	14.8	120	11	11	0.01
				269	14	6	0.08	203	Aug. 23	150	16.0	121	10	9	0.00
				270	12	6	0.08	205	Aug. 24	151	18.6	122	10	10	0.03
100	Jan. 5	284	22.3	265	23	5	0.10					130	8	10	0.01
101	Jan. 6	285	22.3	255	30	5	0.17	207	Aug. 26	153	21.0	124	8	10	0.03
102	Jan. 10	289	22.3	259	12	4	0.13	208	Aug. 28	155	22.3	104	11	14	0.28
				274	12	4	0.08					118	9	12	0.09
				275	10	4	0.06	209	Aug. 29	156	22.3	97	14	12	1.28
				276	11	4	0.07					127	8	10	0.03
103	Jan. 11	290	22.3	260	11	4	0.13	210	Aug. 31	157	22.3	110	10	7	0.13
				270	12	4	0.10	211	Sept. 4	160	22.3	126	9	9	0.03
				275	12	4	0.07					140	7	9	0.01
				280	12	4	0.07	216	Sept. 19	175	29.8	122	8	8	0.26
110	Jan. 30	309	26.2	279	21	4	0.31	217	Sept. 20	176	32.1	149	7	7	0.03
				294	13	0	0.08	219	Sept. 21	177	33.9	120	9	7	0.38
112	Jan. 31	310	26.2	284	13	4	0.26	221	Sept. 27	183	34.7	156	7	7	0.04
				295	23	1	0.17	222	Sept. 28	184	34.7	157	8	8	0.05
114	Feb. 1	311	26.5	295	23	1	0.18	223	Sept. 30	186	34.7	148	7	11	0.11
115	Feb. 2	312	26.8	289	24	4	0.29					163	8	8	0.03
116	Feb. 4	314	26.6	298	22	1	0.18	232	Oct. 20	206	28.1	182	11	4	0.01
130	Mar. 27	5	35.4	339	15	*6*	0.20					189	8	4	0.01
				342	15	*5*	0.17	233	Oct. 21	207	26.0	179	12	4	0.00
132	Mar. 28	6	35.4	335	19	*8*	0.28	236	Oct. 25	211	21.3	164	14	3	0.00
				343	19	*5*	0.25					183	12	3	*0.02*
134	Mar. 29	7	35.4	336	18	*8*	0.29	237	Oct. 30	216	21.3	184	12	2	0.00
137	Apr. 1	10	35.4	339	18	*8*	0.28	238	Nov. 1	218	21.3	179	13	3	*0.03*
				347	18	*5*	0.23					194	10	5	*0.01*
145	Apr. 26	35	34.7	359	17	1	0.54	241	Nov. 20	237	36.3	209	14	3	0.09
147	Apr. 27	36	34.7	5	17	2	0.43					224	11	3	0.05
172	June 30	97	28.4	46	16	11	0.72	243	Nov. 21	238	37.3	214	13	4	0.08
				58	11	8	0.27					229	9	4	0.06
173	July 1	98	27.6	39	22	12	2.78	245	Nov. 25	242	38.0	217	10	2	0.06
				54	15	8	0.33					232	8	2	0.04
				62	10	5	0.19	246	Nov. 27	244	38.0	219	11	3	0.09
175	July 5	102	29.8	47	18	12	1.21					234	9	3	0.06
				62	13	9	0.44								

No. of Chart.	Date. 1854–1855.	Long. of Sun.	Lat. of Obs.	*t.*	Lat. of Bound.		Diff. Absorption.	No. of Chart.	Date. 1855.	Long. of Sun.	Lat. of Obs.	*t.*	Lat. of Bound.		Diff. Absorption.
					N.	S.							N.	S.	
		°	°	°	°	°				°	°	°	°	°	
247	Nov. 28	245	38.0	201	16	4	0.30	304	Mar. 17	355	*22.9*	313	8	8	*0.02*
				231	12	4	0.07					324	7	5	0.00
259	Dec. 19	266	31.0	229	14	10	0.31					332	4	4	0.00
				252	11	6	0.08	306	Mar. 20	358	*22.9*	331	7	6	*0.01*
263	Dec. 21	268	26.0	239	14	7	0.11					334	5	6	0.00
264	Dec. 22	269	23.3	255	11	5	0.05	307	Mar. 21	359	*22.9*	313	7	8	*0.03*
266	Dec. 25	273	17.4	228	11	7	0.00					335	5	6	0.00
				250	9	4	Q.03	309	Mar. 23	1	*22.9*	315	8	8	*0.07*
268	Dec. 26	274	16.0	251	10	5	0.02	309	Mar. 23	1	*22.9*	330	6	7	0.00
270	Dec. 29	277	11.6	232	12	9	0.00					337	5	5	0.00
				254	10	5	0.02	310	Mar. 24	2	*22.9*	316	8	9	*0.08*
271	Dec. 30	278	19.8	255	13	6	0.06					331	7	7	0.00
272	Jan. 1	280	7.4	257	12	7	0.00					339	5	6	0.00
282	Jan. 18	297	*3.7*	263	14	9	*0.07*	311	Mar. 26	4	*22.1*	323	7	8	0.00
				275	10	9	0.00	312	Mar. 28	6	*19.5*	335	7	8	0.00
284	Jan. 19	298	*6.0*	253	16	11	*0.23*					342	6	7	0.01
				276	13	11	*0.02*	313	Mar. 29	7	*17.4*	321	8	8	0.00
286	Jan. 22	301	*12.8*	264	14	9	*0.11*					336	7	7	0.01
				278	12	9	*0.03*					344	6	6	0.01
287	Jan. 23	302	*14.7*	250	16	11	*0.53*	318	Apr. 13	22	18.1	343	11	9	0.76
				279	14	11	*0.04*	320	Apr. 14	23	21.0	345	12	8	0.76
288	Jan. 30	309	*29.1*	264	16	10	*0.37*					356	10	4	0.22
				279	16	7	*0.14*	322	Apr. 16	25	25.5	358	11	9	0.47
297	Feb. 23	333	*52.5*	280	5	9	*0.23*	324	Apr. 17	26	28.0	344	13	6	1.96
298	Feb. 28	338	*40.8*	292	14	10	*0.40*					359	15	6	0.43
299	Mar. 1	339	*39.2*	293	8	11	*0.19*	325	Apr. 18	27	30.5	345	12	6	1.92
302	Mar. 16	354	*22.9*	312	8	6	*0.05*					0	14	6	0.47
				323	7	6	0.00	327	Apr. 19	28	33.2	346	13	5	1.56

The differences of absorption corresponding to the evening observations of the "Stronger Light" at the elongation 60° were likewise computed from the material collected in the previous communication above mentioned. The longitude of the point to which each observation relates was found from the longitude of the Sun. The latitude of the axis, that is, the mean of the two latitudes given for the boundaries of the light, was also computed for each observation.

The evening and the morning observations were then separately arranged in groups, each covering ten degrees of longitude. When the observations forming one of these groups had all been made under similar circumstances, and presented a general resemblance to each other, it was practicable to employ their mean results in the subsequent discussion. But in other cases, parts of adjacent groups were combined to form new groups; no group, however, was made to include more than thirty degrees of longitude. The mean results for all the groups are given in Table II. Those derived from the morning observations are placed by themselves after the others, as is shown in the first column. The second column contains the numbers of the first and last charts employed in forming each group, which are given in order to assist in identifying the portions of previous tables here combined. When the observations of any group were not all made in the same season, the numbers given in the second column will differ considerably. The third column gives the extreme longitudes comprised in each group, and will also assist in identifying the original observations. The next six columns give the number of observations comprised in each group, the mean longitude to which they relate, and the mean results for four other quantities; first,

TABLE II.

Class.	Limiting Nos. of Charts.	Limiting Longitudes.	No. Obs.	Long.	Half Ext.	Diff. Abs.	Incl. Ecl.	Lat. Axis.	Remainders.			Corrected Latitudes.		
									Abs.	Incl.	Lat.	Abs.	Abs.	Incl.
		° °		°	°		°	°		°	°	°	°	°
Evening Observations.	106, 113	5, 11	11	7.6	8.1	0.04	85.5	0.8	*0.68*	54.2	*3.9*	0.3	0.3	0.4
	285, 293	0, 23	7	13.9	9.3	*0.64*	139.7	*3.1*	0.71	*62.1*	4.3	1.0	0.8	0.5
	117, 119	26, 29	9	27.9	7.9	0.07	77.6	1.2	*0.01*	0.2	*0.7*	0.4	0.4	0.3
	120, 124	31, 36	11	33.6	7.7	0.06	77.8	0.5	*0.25*	45.3	*3.0*	*0.2*	*0.3*	*0.4*
	300, 315	53, 79	15	61.9	6.5	*0.19*	123.1	*2.5*	0.35	*50.6*	4.4	*0.7*	*1.0*	*0.1*
	3, 136	57, 75	14	64.5	6.7	0.16	72.5	1.9	0.02	4.5	*0.5*	0.4	0.4	0.6
	138, 326	80, 88	21	84.5	10.2	0.18	77.0	1.4	*0.01*	*12.9*	1.3	*0.3*	0.0	0.5
	140, 149	90, 99	16	93.9	8.0	0.17	64.1	2.7	0.12	*23.0*	1.8	1.1	1.2	0.8
	152, 161	114, 128	15	118.6	7.6	0.29	41.1	4.5	0.43	0.1	1.4	2.1	2.2	0.9
	16, 171	150, 167	18	156.0	11.0	0.72	41.2	5.9	*0.23*	2.2	*0.4*	1.7	1.7	2.3
	179, 190	171, 182	21	176.6	8.0	0.49	43.4	5.5	*0.22*	6.7	*1.1*	2.1	2.3	2.1
	48, 212	200, 229	18	209.8	7.5	0.27	50.1	4.4	*0.02*	*10.6*	*1.3*	2.1	2.3	1.5
	213, 224	230, 258	10	236.0	4.8	0.25	39.5	3.1	*0.04*	16.9	*2.5*	1.0	1.0	*0.5*
	76, 242	270, 298	9	285.2	6.7	0.21	56.4	0.6	*0.01*	*0.5*	0.2	*1.3*	*1.3*	*1.9*
	244, 252	300, 319	10	315.1	5.8	0.20	55.9	0.8	*0.08*	10.0	0.5	*1.0*	*1.0*	*1.7*
	88, 262	320, 329	17	324.6	5.7	0.12	65.9	1.3	*0.08*	15.5	*0.8*	*0.1*	0.1	*0.5*
	89, 265	330, 338	13	336.6	8.4	0.04	81.4	0.5	*0.06*	14.0	*1.3*	0.0	0.0	*0.2*
	96, 276	342, 349	13	346.5	7.4	*0.02*	95.4	*0.8*	*0.05*	7.1	*0.7*	*0.3*	*0.4*	*0.4*
	104, 283	350, 358	24	353.7	7.9	*0.07*	102.5	*1.5*	0.11	*17.0*	2.3	*0.4*	*0.5*	*0.6*
Morning Observations.	13, 173	23, 38	6	35.1	10.6	0.76	49.7	2.1	*0.34*	*0.4*	*0.5*	*2.4*	*1.7*	*2.7*
	30, 178	42, 56	15	48.6	9.0	0.42	49.3	1.6	*0.21*	18.9	*0.2*	*1.5*	*1.3*	*3.3*
	42, 195	61, 72	14	65.7	10.2	0.21	68.2	1.4	*0.09*	13.6	*1.5*	*0.5*	*0.3*	*1.2*
	43, 211	83, 108	20	95.7	9.2	0.12	81.8	*0.1*	*0.06*	0.6	0.3	*1.3*	*1.0*	*1.1*
	55, 223	111, 129	19	120.1	6.4	0.06	82.4	0.2	*0.06*	7.5	1.9	*0.5*	*0.4*	*0.8*
	66, 238	130, 159	16	148.3	6.3	0.00	89.9	2.1	0.08	*15.5*	1.4	2.1	2.2	2.1
	85, 247	165, 185	12	178.5	7.3	0.08	74.4	3.5	*0.01*	3.3	*1.3*	2.6	2.7	1.5
	90, 271	206, 219	18	214.5	8.9	0.07	77.7	2.2	0.03	*6.2*	2.3	1.4	1.4	0.8
	97, 103	222, 230	15	226.5	9.6	0.10	71.5	4.5	*0.24*	30.1	*2.4*	3.4	3.5	2.3
	272, 288	220, 249	11	239.5	11.7	*0.14*	101.6	2.1	0.35	*43.3*	6.5	3.5	3.3	3.5
	110, 116	249, 254	7	250.7	11.0	0.21	58.3	8.6	*0.28*	42.9	*8.6*	6.7	6.7	4.8
	297, 307	273, 299	12	291.4	7.1	*0.07*	101.2	0.0	0.06	*10.6*	*0.2*	0.8	0.7	1.3
	309, 313	301, 307	12	303.8	6.9	*0.01*	90.6	*0.2*	0.25	*56.7*	12.2	*0.1*	*0.1*	*0.1*
	130, 137	305, 310	7	307.0	5.5	0.24	33.9	12.0	0.63	5.6	*8.2*	9.9	9.9	5.4
	145, 327	322, 336	11	327.1	9.4	0.87	39.5	3.8	*0.11*	10.2	*1.7*	*1.1*	*0.8*	*2.2*

half the sum of the latitudes of the boundaries, here designated as half the extent of the light; second, the difference of absorption at the boundaries, expressed as in Table I.; third, the zenith distance of the north pole of the ecliptic, here called the inclination of the ecliptic; and fourth, the latitude of the axis, as above defined. The next three columns, headed "Remainders," contain differences found from the three preceding columns, by subtracting the quantities given in each line from those in the next line below. The remainders in the last lines of the evening and morning observations are found by subtracting the quantities contained in them from those in the corresponding first lines. A system of corrections, which will be explained below, was derived from these remainders. The three final columns of Table II. contain corrected values for the latitude of the axis. The first two of these columns result from corrections determined by the difference of absorption; the same system of corrections is respectively applied in the two cases to the mean values in Table II., and to the separate observations from which these mean values were derived. There is no material difference in the result of these methods. The corrected latitudes in the last column are determined by the inclination of the ecliptic, instead of by the difference of absorption; the corrections were applied to the mean values in Table II. As in Table I., negative quantities are indicated by Italic figures.

We know already that the latitude of the axis varies to some extent in accordance with the difference of absorption at the boundaries of the light, as well as with the inclination of the ecliptic, and it is obvious that Table II. exhibits variations of this kind. We should presumably find similar relations between the latitude of the axis and the mean of the amounts of absorption at the boundaries, or their ratio; but there is little reason to suppose that any function of the absorption would be better adapted to the present purpose than the difference here employed. As there is some probability that atmospheric absorption is a physical cause of the changes of position observed in the zodiacal light, it may be well to begin by making the proposed system of corrections depend upon the difference of absorption, and afterwards to form another system, dependent upon the inclination of the ecliptic. After some allowance for the effect of absorption has been made by estimation, Table II. seems to indicate the existence of additional changes in the latitude of the axis, dependent upon the longitude. In attempting to obtain numerical corrections for the effect of absorption, we must accordingly compare the results furnished by groups of observations at longitudes not too widely separated. At the same time it does not seem advisable to confine the comparisons to the few adjacent groups which differ only a little in longitude, since the unsystematic variations are evidently large. The remainders in absorption and latitude, given in Table II., were therefore adopted as the basis of the corrections.

The first step taken was to change the signs of corresponding remainders when necessary, so that those derived from the differences of absorption might all be positive. Among the nineteen remainders in latitude formed from the evening observations only four were then negative, and the corresponding remainders in absorption were small. Four negative quantities also occurred among the fifteen remainders in latitude formed from the morning observations. One of them corresponds to a large remainder in absorption; this is due to the influence of an abnormal group of observations, which will again be mentioned. The general agreement of the signs illustrates the dependence of the latitude upon the effects of absorption; but the variations in the relative magnitude of the remainders are too irregular to allow a satisfactory system of corrections to be immediately apparent from a graphical arrangement of the data. In order to avoid the possible effects of prejudice, without adopting a process involving more labor than would be warranted by the degree of accuracy to be expected in the result, the remainders derived from the differences of absorption were next arranged, according to their magnitude, in groups of five each, so far as practicable, and the corresponding remainders in latitude were also collected. In this manner four groups were formed from the evening observations, and three from the morning observations. In each part of Table III. the successive columns give the number of remainders in each group, their sums, their mean values, and their average deviations from these means.

TABLE III.

Evening Observations.							Morning Observations.						
No. Rem.	Sums.		Means.		Av. Dev.		No. Rem.	Sums.		Means.		Av. Dev.	
	Abs.	Lat.	Abs.	Lat.	Abs.	Lat.		Abs.	Lat.	Abs.	Lat.	Abs.	Lat.
		°		°		°			°		°		°
5	0.07	0.0	0.01	0.0	0.01	0.8	5	0.22	1.2	0.04	0.2	0.02	1.2
5	0.31	4.8	0.06	1.0	0.01	0.7	—	—	—	—	—	—	—
5	0.93	8.6	0.19	1.7	0.06	0.8	5	0.73	7.2	0.15	1.4	0.06	0.5
4	2.17	14.0	0.54	3.5	0.15	1.0	5	1.85	19.6	0.37	3.9	0.10	6.2

The first and second groups of remainders from the morning observations agree so nearly with the first and third of those obtained from the evening observations that there seems to be no reason, so far as these groups are concerned, for adopting different systems of corrections in the two cases. The third group of morning observations approximately agrees with the fourth group of evening observations in the mean result for latitude, but not in that for absorption. This might suggest the use of different systems of corrections for the two series of observations, if the large average deviation in latitude, 6°.2, from the group under consideration did not show that very little relative weight can be attributed to the corresponding mean; for the average deviation in absorption, belonging to the same group, is not remarkably large. The relative weights of the means in latitude for the final groups of evening and morning observations, if computed by the ordinary rule,[1] would be 26 and 1. Under these circumstances, the discordant mean can hardly be used independently. Out of the five remainders from which it is derived, four are affected by two peculiar groups of observations in Table II. Each of these groups consists of seven observations, made about the same time. The limiting numbers of the charts for the first group are 110, 116, and for the second 130, 137. An examination of these charts, in the original work of Jones, will show that his observed positions of the eastern zodiacal light on the corresponding dates were really exceptional, and indicate the action of special causes, which cannot be traced at present. In the method of reduction here employed, the second of these abnormal groups of observations accidentally counteracts to some extent the effect of the other; for this reason the result may perhaps be allowed a small weight, instead of being rejected, as it would practically be with a weight of $\frac{1}{26}$. The course adopted was to combine the fourth group of evening and the third of morning observations with the relative weights 40 and 5; to combine with equal weights the first groups of evening and morning observations, as well as the third group of evening and the second of morning observations; and to employ the second group of evening observations independently. The four sets of mean remainders thus obtained are as follows:—

Variation in absorption.	Corresponding variation in latitude.
0.029	0°.12
0.062	0 .96
0.166	1 .58
0.523	3 .55

---

[1] Chauvenet, Spherical and Practical Astronomy, II. 494, 505.

If these results are laid down as points determined by rectangular co-ordinates, the abscissas representing the variations of absorption, expressed in tenths of a magnitude, and the ordinates representing variations in latitude, expressed upon the same scale in degrees, a curve passing through the origin and nearly through the projected points may be drawn with some confidence; but beyond the extreme point its course would be doubtful. Hence it seemed best to employ a curve of some simple theoretical form suggested by the graphical result. The curve selected was a parabola passing through the origin, with its axis parallel to the axis of abscissas. Upon this assumption, the mean values just obtained for the corresponding variations in absorption and in latitude will furnish four equations of condition, of the form $p\,x + b\,y = \frac{1}{2}\,y^2$, if we denote by $2\,p$ the parameter of the parabola, and by $-b$ the ordinate of the vertex. The solution of these equations by the method of least squares results in the values $2\,p = 4.77$ and $b = 1.70$. Hence the abscissa of the vertex is -0.61, and the equation of the parabola is $(y + 1.70)^2 = 4.77\,(x + 0.61)$, from which values of y in degrees may be obtained for values of x given in tenths of a magnitude. This parabola was charted, and the corrected latitudes, entered in the two columns of Table II. next to the last, were mostly found from the chart.

Results previously reached by other methods for the relation between absorption and latitude did not materially differ from those just given. The method here adopted has the advantage of leaving comparatively little to be arbitrarily determined.

The experiment was afterwards made of grouping the remainders derived from the inclination of the ecliptic and from the latitude of the axis in Table IV., the form of which resembles that of Table III.

TABLE IV.

Evening Observations.							Morning Observations.						
No. Rem.	Sums.		Means.		Av. Dev.		No Rem.	Sums.		Means.		Av. Dev.	
	Incl.	Lat.	Incl.	Lat.	Incl.	Lat.		Incl.	Lat.	Incl.	Lat.	Incl.	Lat.
	°	°	°	°	°	°		°	°	°	°	°	°
5	7.5	0.4	1.50	0.08	1.5	0.6	5	16.1	11.0	3.22	2.20	2.2	2.4
5	47.3	1.3	9.46	0.26	2.0	0.9	5	58.0	2.5	11.60	0.50	2.6	1.3
5	86.4	8.7	17.28	1.74	2.3	0.6	—	—	—	—	—	—	—
4	212.2	15.6	53.05	3.90	5.1	0.4	5	191.9	29.9	38.38	5.98	11.1	3.7

Other groupings were also tried. In all cases the evening observations seem to be sufficiently accordant, but the morning observations so much more irregular than when they were grouped according to variations of absorption that they cannot be advantageously combined with the evening observations. An attempt to do this gave corrections for the evening observations, which themselves unmistakably required systematic correction for the inclination of the ecliptic. For the evening observations separately a uniform system of corrections, represented graphically by a straight line from the origin through the point corresponding to the fourth group in Table IV., appeared to be as satisfactory as any. The corrected latitudes given for the evening observations in the last column of Table II. were thus obtained. For the morning observations, the quantities in the same column were obtained from a system of corrections represented by a straight line from the origin through the point corresponding to the mean of the final groups of evening and morning observations in Table IV. The choice of this point is arbitrary, and the result, accordingly, uncertain.

The three columns of corrected latitudes in Table II. exhibit systematic variations dependent upon the longitude, and both the evening and the morning observations agree in placing the axis of the light in north latitude for about fifty degrees on each side of the autumnal equinox. Near the vernal equinox the results are more irregular, with a tendency to south latitude. Our present knowledge does not warrant the assumption that the axis should lie on any great circle; on the other hand, we should not be entitled to regard the results of the evening observations as showing that the axis crosses the ecliptic more than twice. But after making any reasonable allowance for error in the observations and in the method of reduction, it can hardly be doubtful that the axis of the "Stronger Light," as seen by Jones at the elongation 60°, was decidedly north of the ecliptic near the autumnal equinox, and considerably farther south, if not actually in south latitude, near the vernal equinox. It will appear on examination that only an obviously excessive correction for absorption or for the position of the ecliptic will remove the evidence of this variation in the evening observations, while it happens in the case of the morning observations that those made near the autumnal equinox cannot be subject to large corrections on any system.

It will now be interesting to compare this result with one obtained from observations of the faint light, called "Gegenschein," and occasionally seen in approximate opposition to the Sun. Its centre is usually somewhat to the north of the ecliptic, which may indicate an effect of atmospheric absorption; but this question cannot well be determined without the aid of observers stationed in the southern hemisphere, while hitherto the light has been seen only at northern stations. From some observations collected upon a former occasion, however, it appears that, near the vernal equinox, the observed position of the light is occasionally south of the ecliptic, while between the longitudes 140° and 220° it often attains a greater north latitude than elsewhere. It was the conclusion thus reached that led to the present inquiry with regard to the position of the zodiacal light according to the observations of Jones. The agreement of the two results may make it worth while to repeat in a condensed form a list of mean positions for "Gegenschein" given in the article just mentioned.[1] The headings λ and β indicate approximate longitudes and latitudes. The mean result for each column is given at its foot.

λ	β	λ	β	λ	β	λ	β	λ	β	λ	β
°	°	°	°	°	°	°	°	°	°	°	°
137	+2	160	+2	188	+3	213	+3	341	0	10	−3
150	+3	165	+1	189	0	220	0	342	+2	13	−2
150	+5	170	0	192	+2	220	0	345	+2	18	−1
152	+6	170	+1	199	0	223	0	351	−2	34	+2
154	+3	176	0	204	+1	229	−2	356	0	....	
157	+4	181	0	208	0	.....		3	−1	....	
150	+4	170	+1	197	+1	221	0	350	0	19	−1

If any corrections for absorption could be applied to these latitudes, they would presumably all be negative, and numerically smaller in the first, second, and sixth columns than in the others, since the observations were all made near the meridian. Hence the difference between the first column and the rest would rather be increased than diminished by the corrections. There is accordingly no similarity in detail between these results and those of Table II., while their general resemblance is obvious. It will afford an additional reason for regarding the latitude of the zodiacal light as actually variable in accordance with its longitude. The strength of this reason will depend upon the degree of confidence which may be felt in the actual appearance of part of the zodiacal light in the form of "Gegenschein."

Although this faint light in opposition to the Sun has been seen by very few observers, some of them have expressed great confidence in its existence, and it has been three times independently discovered, — by Brorsen,[2] Backhouse,[3] and

---

[1] Astronomische Nachrichten, CIX. 259.

[2] Astronomische Nachrichten, XLII. 219.

[3] Monthly Notices of the Royal Astronomical Society, XXXVI. 46.

Barnard.[1] It so happens that those who see the phenomenon best have been prevented by other occupations from observing it frequently and with precision, or at least from publishing in detail, and in some generally accessible place, the observations which they may have made. But in view of the triple discovery of "Gegenschein," and of the considerable, though fragmentary, mass of published observations respecting it, little doubt can be felt of its reality. Assuming it to exist, the probability that it is part of the zodiacal light is certainly strong, although there is no easy theoretical explanation of its appearance. The readiest way of accounting for it, on the meteoric theory of the zodiacal light, would be to assume such a law for the phases of the meteors that their brightness would rapidly increase as they approached opposition. Some indications of the possibility of such an increase have been given in a former communication.[2] A less natural explanation might be sought in the possible perturbations of meteoric matter by the Earth.[3]

The conclusion that the zodiacal light lies farther to the north near the autumnal than near the vernal equinox may accordingly be regarded as considerably strengthened by the agreement between the observations of "Gegenschein" and those made by Jones of the brighter portions of the zodiacal light. In any future observations of either kind, it will be interesting to notice whether further evidence in support of this conclusion is obtained. Perhaps it will also be possible to define the position of the light more accurately than could be done by the older methods of observation, and to trace any progressive changes which may occur in it.

The main hindrance to the development of the meteoric theory of the zodiacal light is the want of trustworthy information with regard to the probable phases of the meteors. Writers who have attempted to treat the subject mathematically[4] have hitherto contented themselves with Lambert's formula, $\sin v - v \cos v$, which has a very imperfect foundation in experiment, and does not apply to the phases of rough bodies, even if the hypotheses on which it rests are correct. Experiments are now in progress, however, at the observatories of Munich[5] and of Harvard College, which may add considerably to our knowledge of the laws of irregular reflection. After enough information of this kind has been collected,

---

[1] Sidereal Messenger for November, 1883, II. 254.

[2] Proceedings Am. Acad., XIX. 310.

[3] Astronomische Nachrichten, CII. 266.

[4] Schiaparelli, Entwurf einer astronomischen Theorie der Sternschnuppen (German translation by Boguslawski), p. 194; Geelmuyden, Remarques sur la théorie de la lumière zodiacale, p. 104.

[5] Vierteljahrsschrift der Astronomischen Gesellschaft, XX. 111.

it will become more practicable to compute the theoretical amounts of light at various elongations which would result from any given hypothesis with regard to the distribution of meteors in the Solar System.

In any such computation, it will probably be found that between the vertex of the ordinary zodiacal light and the region at the elongation 180° the light will remain nearly constant for a considerable arc of longitude. This, at least, was the result of some unpublished computations, made a few years ago upon various hypotheses of the distribution of the meteors and the effect of their phases. The existence of the zodiacal band, reported by Brorsen, Schmidt, and other observers, would be wholly consistent with this conclusion; but it is still a little uncertain whether the observed zodiacal bands may not be due to faint streams of stars. It rather singularly happens that on both sides of the Milky Way the existence of such streams is indicated by the Durchmusterung. The narrow band from the Pleiades has been fully discussed elsewhere,[1] and on recent examination it appeared that a similar stream of Durchmusterung stars extends along the ecliptic from ϵ *Cancri* to β *Virginis.* The region examined was that portion of the Durchmusterung from $8^h\ 0^m$ to $13^h\ 0^m$ in right ascension, and from $-2°$ to $+28°$ in declination. Within this region, the number of stars in each 4^m of right ascension was counted for each degree of declination, and, north of $+12°$, these numbers were multiplied by the secants of the corresponding declinations. The numbers thus corrected represent observed stellar densities, the unit of area being the square degree, but the corrections are everywhere small. With the aid of Dien's Atlas, the epoch of which, 1860, is sufficiently near that of the Durchmusterung for the present purpose, a line was laid down through the region along the middle of the assumed course of a permanent band of faint light, which appears to me to be visible there.[2] Several other lines were drawn at distances of two and a half degrees apart, on either side of the principal line. For each hour of right ascension, the corrected number of Durchmusterung stars in each square degree intersected by the lines was taken from the list previously prepared, and the mean result was found for each line. These means, which are given in Table V., do not support the hypothesis that the observed band is due to an accumulation of stars, except in the first part of its course, where it is obliquely intersected by the ecliptic. The first column of Table V. gives a number for the designation of each line; the principal line is No. 5, and is drawn through ϵ *Cancri* to o *Leonis,* thence south of the ecliptic so as to pass about

---

[1] Astronomische Nachrichten, XCIX. 91, 369.

[2] Astronomische Nachrichten, CII. 265.

midway between σ and φ *Leonis*, and afterwards to *Coma Berenices*. The other columns are divided into groups of three for the successive hours of right ascension. In each group the first column gives the number of square degrees crossed by the line, the declination of the southern border of the first square, in Italics if negative, and the mean number of stars to the square degree. The vacant spaces show that the course of the lines sometimes carries them beyond the adopted limits of declination.

TABLE V.

No. of Line.	8^h.			9^h.			10^h.			11^h.			12^h.		
	No.	Decl.	Mean.	No.	Decl.	Mean.	No.	Decl.	Mean.	No.	Decl.	Mean.	No.	Decl.	Mean.
		°			°			°			°			°	
1	19	14	13.1	12	3	11.2	—	—	—	—	—	—	28	*2*	8.9
2	22	17	13.5	22	6	10.7	—	—	—	5	*2*	10.6	31	0	8.1
3	22	20	15.9	21	9	10.2	8	0	9.4	11	*2*	9.1	32	3	9.4
4	19	23	16.2	19	12	9.6	15	3	8.1	19	*1*	9.3	27	6	7.9
5	21	26	16.7	21	15	11.0	17	6	8.7	17	1	8.8	22	10	7.8
6	20	27	14.0	19	17	12.9	16	8	9.9	20	4	7.2	19	14	7.4
7	12	27	11.0	21	20	12.6	18	11	10.0	23	6	7.7	10	20	9.9
8	7	27	11.0	19	23	11.3	17	14	10.4	24	9	8.0	3	25	10.3
9	2	27	7.0	20	26	11.1	17	16	8.0	25	11	9.7	—	—	—
10	—	—	—	15	27	10.5	18	19	9.4	22	14	9.1	—	—	—
11	—	—	—	11	27	10.9	16	22	9.7	16	16	8.9	—	—	—
12	—	—	—	6	27	7.3	18	24	9.7	10	19	10.1	—	—	—

In 8^h, 9^h, and 10^h there is a slight maximum of stars, which appears later in the series of lines in each successive hour. If the position of the lines is examined, it will appear that the maximum approximately follows the course of the ecliptic. The lines run northward in 11^h and 12^h, so that for these hours no indication is given in Table V. of the relative frequency of stars near the ecliptic, and it only appears that the stars of the Durchmusterung are relatively few upon the course of the supposed band. If other observers should consider that any band of faint light occurs there, the possibility of a diffused nebulosity in this part of the sky (which abounds in telescopic nebulae), might be suggested.

Another faint band of light[1] appears to me to be situated south of β and η *Virginis*. This region is too near the southern limit of the Durchmusterung to allow the distribution of stars in it to be well studied from that catalogue. But so far as evidence can be obtained from it by the method above explained, it would seem that along the line passing approximately through β and η *Virginis*

---

[1] Astronomische Nachrichten, CIX. 262.

themselves, which nearly coincides with the ecliptic, the number of Durchmusterung stars to the square degree is slightly greater than on other lines parallel to it on each side. To complete the inquiry thus suggested, straight lines were laid down on the chart between the limits of right ascension $10^h\ 0^m$ and $12^h\ 0^m$, with the following limits in declination: $+6°$ to $-5°$; $+8°$ to $-3°$; $+10°$ to $-1°$; $+12°$ to $+1°$; $+14°$ to $+3°$; $+16°$ to $+5°$; $+18°$ to $+7°$. The first two of these lines extend beyond the limits of the Durchmusterung. The numbers of square degrees within these limits which are intersected by the lines are respectively 26, 32, 36, 36, 36, 36, 36; and the corresponding mean numbers of Durchmusterung stars to the square degree are 9.0, 9.7, 10.0, 9.9, 9.3, 8.5, 8.4. Here again a slight maximum is indicated for the vicinity of the ecliptic. It accordingly seems to be a fact, so far as it can be determined by the Durchmusterung, that there is a slight relative abundance of stars all along the ecliptic between the limits of right ascension $8^h\ 0^m$ and $13^h\ 0^m$. This conclusion is confirmed by inspection of the Durchmusterung atlas. It is not at present to be assumed that the distribution of the fainter stars follows the same rule, or that the slight variations of stellar density here found are sufficient to be distinguishable to the eye of an observer; still, considering the faintness of the zodiacal bands occasionally reported, their nature may perhaps be rendered a little doubtful by the statistics of the distribution of Durchmusterung stars which have just been considered. In time to come, photography may resolve some of the difficulties now attending inquiries of this kind.

The orbits of the known asteroids naturally suggest themselves as another possible source of information with regard to the distribution of light in the zodiac. The discovery of so many small planets between Mars and Jupiter makes it seem somewhat probable that large quantities of meteoric dust may circulate in the same region, and in orbits similar to those of the separately visible objects which have been found there. The appearance of this dust from a distance might have a general resemblance to that which would result if the asteroids left permanent traces of light behind them in their movements. But in attempting to determine this effect from the orbits of the asteroids hitherto discovered, it must be remembered that the circumstances under which the search for them has been conducted may produce apparent peculiarities in their distribution.

The elements of the first 237 asteroids, as given in the Berlin Jahrbuch for 1887, have accordingly been examined with some care, and several tabular arrangements of these elements have been formed, to exhibit any peculiarities which they might present. Upon the whole, it does not seem necessary that the details of these investigations should here be given at length, since it is not certain that the classification employed would be serviceable to other inquirers, and since the rapid discovery of new planets would soon deprive the results thus exhibited of any appearance of completeness. It will perhaps be interesting, however, to state the general conclusions which were obtained from the tables.

Upon the comparison of elements published twenty or thirty years ago with others computed for recent epochs, it appears that the orbits of asteroids do not generally vary with such rapidity as to invalidate, in the course of half a century at least, any statistical results like those here described. The distribution in longitude of the ascending nodes of the known asteroids was the first subject of inquiry, and the conclusion was obtained that the zodiacal band formed by the collective orbits would have its least extension in north latitude about the longitude 0°, and its least extension in south latitude about the longitude 180°. The coincidence of this result with that already found for the zodiacal light induced me to try the effect of a stereographic projection of the northern halves of the orbits on the plane of the ecliptic. In this projection, the nodes and inclinations of the orbits were the only elements employed, so that the supposed band was regarded as seen from the Sun. The radius of the projection was five inches. Upon this scale a distinct band of shading was formed by the lines representing the orbits of the first 120 asteroids; the remaining 117 were laid down upon a separate chart. Both charts, but especially the first, exhibited a depression of the edge of the band in the region near the longitude 0°, as had been expected. The same charts will also represent the southern halves of the orbits if we regard all the longitudes as increased by 180°.

Farther examination showed that the asteroids to which this peculiarity is due are those having their perihelia in south latitude. The general result thus obtained may be sufficiently well exhibited by stating the number of ascending nodes for each quadrant of longitude, beginning at 40°, which occur in the orbits of asteroids having their perihelia respectively in north and in south latitude.

Longitudes of ascending nodes.	40° to 130°.	130° to 220°.	220° to 310°.	310° to 40°.
Perihelia in north latitude . . .	23	40	23	45
Perihelia in south latitude . . .	32	38	6	30
Total	55	78	29	75

The band formed by the collective orbits with perihelia in north latitude, accordingly, would not have any distinct tendency towards north and south latitude in different quadrants, although its width might vary. The two maxima and minima may probably be explained by the consideration that discoveries of asteroids are usually made near opposition, and are more likely to be made near a node than elsewhere. Such discoveries, with unimportant exceptions, have hitherto been made in Europe or in the United States, where the weather and the position of the ecliptic in the visible hemisphere make the winter and summer months less favorable than the spring and autumn to the search for new planets. In Chambers's Astronomy, edition of 1877, the dates of discovery of the first 169 asteroids are given: 51 occur in March, April, and May; 35 in June, July, and August; 62 in September, October, and November; and 21 in December, January, and February. Hence the asteroids most likely to be discovered have hitherto been those having nodes in the parts of the ecliptic which come into opposition in autumn and spring.

But since a planet may apparently be discovered as readily near one of its nodes as near the other, the peculiar distribution of the nodes of the orbits with southern perihelia cannot easily be explained by the circumstances under which the discoveries have been made. There is, however, no very strong reason to think that it indicates any systematic peculiarity in the orbits of asteroids in general; for we see that the reversal of the nodes of only thirteen orbits would be enough to eliminate it from the statement just given of the number of ascending nodes in different quadrants. Still, this number, thirteen, is about one eighteenth of the total number of orbits under discussion, so that it is not relatively insignificant, although it is evident that the discovery of a much larger number of small planets than are now known will be desirable for determining the question whether there is any marked irregularity in the distribution of the nodes of such objects in general.

If we assume that the distribution of the nodes, in the case of meteoric particles at about the distance of asteroids, is correctly indicated by the asteroids already known, it follows that the zodiacal band formed by their collective orbits would show a tendency to north latitude at the longitude 180°, and to south latitude at 0°; for the deficiency of ascending nodes in the quadrant from 220° to 310° would occasion a deficiency of extreme north latitudes in the quadrant from 310° to 40°, and a similar deficiency of extreme south latitudes in the quadrant from 130° to 220°. Moreover, the tendency to north latitude at 180° would be stronger than that to south latitude at 0° if the entire effect were due to particles having perihelia in south latitude; for, in that case, the deficiency in south latitudes in the quadrant from 130° to 220° would be enhanced by the deficiency of perihelia, even when viewed from the Sun. To a terrestrial observer, the effect would be still farther increased by the result of parallax, when the region observed was in opposition. The coincidence of this theoretical result with that derived from the observations of "Gegenschein" is not for the present to be regarded as anything more than a suggestion, which may lend additional interest to future observations of light in the zodiac, and also to the discovery of more small planets, which is often regarded as leading to no result of consequence.

The six asteroids having southern perihelia, and ascending nodes between the longitudes 220° and 310°, are Hygiea (10), Pomona (32), Aethra (132), Polana (142), Xanthippe (156), and Loreley (165). The orbit of Aethra has a large inclination and eccentricity; those of the five others are not distinguished by any peculiarity except that of the position of their nodes. The approximate longitudes of the ascending nodes of these planets are respectively 286°, 221°, 260°, 292°, 246°, and 304°; the corresponding values of the angles in the planes of their orbits by the amounts of which their perihelia follow their ascending nodes are 311°, 333°, 253°, 289°, 270°, and 333°.

Upon the hypothesis that a noticeable amount of light is reflected to us by meteors not more than two or three times farther from the Sun than we are, this light would vary its position in longitude according to its elongation. At its eastern elongation it would precede its heliocentric longitude, which it would follow at its western elongation. Applying these considerations to the case of the evening and morning zodiacal light, we see that if the light would tend to south latitude at the longitude 0° as seen from the Sun, then, as seen from the Earth, and at the elongation 60°, the evening zodiacal light should be farthest to the south at the longitude 340° or still sooner, while the morning light should have its greatest southern latitude at 20° or later. A similar effect of parallax might be expected at the maximum of north latitude. A reference to Table II. will show that indications of these effects are in fact presented by the observations of Jones. The coincidence is worth attention, although the uncertainty of the correction for atmospheric absorption employed in Table II. makes it difficult to obtain more than a general conclusion from the corrected latitudes.

It has been shown that the symmetrical part of the variation noticed above in the number of ascending nodes at different longitudes may perhaps be due to the circumstances under which asteroids have been discovered. But if we suppose it to indicate a general tendency of such bodies, the band which they would form should be narrower near the longitudes 0° and 180° than near the longitudes 90° and 270°. The column in Table II. giving half the extent of the zodiacal light in latitude was inserted in order to exhibit any striking variations in the dimensions of the light at different longitudes. The variations which appear in it, however, are not large enough to allow any safe inference from them, unless we could correct them like the latitudes, which seems to be impracticable. They have some relation to the changes in the difference of absorption at the boundaries, but this would naturally result from the manner in which the difference of absorption was determined. When the light was observed to be wide, the computed difference of absorption is of course larger than when the observed light, under similar circumstances, was relatively narrow. On comparing the observed width with the corresponding results for the inclination of the ecliptic to the horizon, no systematic variation was detected. It seems probable that the width of the light, as observed by Jones, was subject to considerable variation on account of the meteorological conditions prevailing at the time of observation. As the observations were made in various climates and at all seasons of the year, there is little reason to expect from them the discovery of any systematic variation in the width of the light, dependent either upon its zenith distance or upon its longitude.

Besides the longitudes of the ascending nodes, the other elements determining the form and position of the orbits of asteroids were discussed, but without many results here requiring notice. The inclinations do not appear to depend upon the longitudes of the nodes, the relative proportions of small and large inclinations not showing any marked changes at different longitudes. In all, the number of inclinations less than 5° is 78; between 5° and 10°, 86; between 10° and 15°, 45; greater than 15°, 28. We may probably infer that the band formed by the collective orbits would approach the latitude of 10°, north and south, with little diminution of brightness, and would afterwards become fainter rather rapidly. But it should be remembered that asteroids with large inclinations are less likely than others to be discovered.

The longitudes of the perihelia, using that term in the customary sense, show a tendency to accumulate near the vernal equinox. Between 300° and 60° there are 122 perihelia, while in the remaining 240° of longitude there are only 115. It is not easy to explain this peculiarity by the circumstances under which asteroids have been found. If it indicates a real inequality, the band formed by the collective orbits should on the whole be relatively bright, and, in opposition, relatively wide, near the longitude 0°. The zodiacal light usually attracts most attention by its brilliancy near that longitude; but we need careful photometric observations in both hemispheres to determine whether this apparent brilliancy is not wholly due to the favorable position of the zodiac in the sky of the northern hemisphere during the evenings at the end of winter.

No remarkable relation between the longitudes and latitudes of the perihelia was noticed. The accumulation just mentioned occurs both in north and in south latitude. The mean distances and eccentricities, also, are not apparently connected by any relation with the longitudes of the perihelia. There is a slight preponderance of large eccentricities with perihelia in north latitude between the longitudes 300° and 360°, and a similar preponderance of large eccentricities with perihelia in south latitude between the longitudes 0° and 60°.

The number of perihelia in north latitude is 131, in south latitude 106. As asteroids will be most readily discovered near their perihelia, and at a considerable altitude, the excess of perihelia in north latitude may be due to the northern stations of the discoverers. This consideration, however, fails to account for the remarkable distribution of the ascending nodes of asteroids with southern perihelia which has already been discussed.

The principal fact noticed with regard to the mean distances was that the more recently discovered asteroids have on the whole larger mean distances than the others, as might naturally be supposed. Taking the distance for which $\log a = 0.437$ as the limit between small and large distances, we find among the first 120 asteroids 71 relatively near, and 49 remote; the corresponding numbers for the next 117 are 51 and 66. It is also noticeable that the remoter asteroids have less eccentric orbits than the rest. If the value of the eccentricity for which $\phi = 9^\circ$ is taken as the limit, there are 57 of the nearer asteroids with orbits of small eccentricity, and 65 with decidedly eccentric orbits; for the remoter asteroids the corresponding numbers are 67 and 48. But these peculiarities have no apparent connection with the present subject.

It may be shown mathematically that if the zodiacal light is due to meteoric dust diffused through the Solar System, those particles far beyond the orbit of Jupiter can add little to its brightness, upon any reasonable hypothesis with regard to the distribution of the meteors. But at mean distances of 2 or 3, the effect would not be relatively insignificant, and the existence of the asteroids, as has been said, suggests the possibility that very minute planets may accompany them in large numbers. It scarcely needs to be said that meteoric dust in the region of the asteroids cannot account for all the phenomena of the zodiacal light; we must in any case suppose that a great part of the light comes from particles much nearer to the Sun.

The various resemblances between different groups of phenomena which have been pointed out in the preceding pages may be entirely fortuitous, and should not be regarded as a satisfactory basis for any theory of the zodiacal light. But it is only by taking notice of such resemblances when they occur that we can be guided in subsequent observations. This consideration appears to me sufficiently important to justify the foregoing discussion. Perhaps the results above described might be either invalidated, or decidedly confirmed, by additional examination of the published work of observers of the zodiacal light, and especially of the material provided by the energy of Jones. But the labor to be undertaken in the necessary reductions is considerable, and the corrections to be applied must remain uncertain. Accurate knowledge of the phenomena of the zodiacal light can be expected only from photometric observation. To whatever extent these difficulties may hinder the derivation of additional knowledge from the work of Jones, his memory will always be honored for the unusual assiduity which he displayed in observations of the zodiacal light, and for his discovery of the first law tending to explain its apparently irregular phenomena.

Cassini's opinion, that the axis of the zodiacal light lies in the plane of the Sun's equator, was partly founded upon observation. But the observations by Cassini, quoted by Jones at the end of his work, are insufficient to establish any such conclusion. It seems from them, however, that Cassini saw the light generally farther to the north in Leo and Virgo than in Pisces and Aries, even after making some allowance for the effect of absorption. This effect, on the other hand, would sufficiently explain the northward tendency of the light during the month of April, which suggested to Cassini the hypothesis above mentioned. On merely theoretical grounds it has some claim to consideration; for it is possible that the rotation of the Sun indicates the fundamental plane of the Solar System, if we accept the ordinary nebular hypothesis of its formation, more correctly than can be done by the revolutions of the known planets. Since the longitude of the ascending node of the Sun's equator is about 75°, the results of the present inquiry agree tolerably well with Cassini's hypothesis.

The reduction of fifty-eight observations, by various observers, of the vertex of the zodiacal light, made by Houzeau in 1844,[1] gave for the longitude of its

---

[1] Astronomische Nachrichten, XXI. 186.

ascending node 2°, with the inclination 4°. In the present state of our knowledge upon the subject, this result cannot be regarded as significant, since the material employed was necessarily insufficient.

The principal conclusions reached in the present communication may now be recapitulated as briefly as possible:—

1. It is probable that atmospheric absorption largely affects the apparent position of the zodiacal light.

2. After allowance for the effect of absorption, there is reason to think that the zodiacal light, as seen during the second half of the nineteenth century, has had a more northern latitude near the longitude 180° than near the longitude 0°.

3. Upon the meteoric theory of the zodiacal light, it is to be expected that a continuous zodiacal band should be present; but the question of its actual visibility is complicated by the slight maxima of stellar density which are situated along those parts of the ecliptic most readily accessible to observation from stations in the northern hemisphere.

4. The belt of sky occupied by the projections of the orbits of the first 237 asteroids presents certain peculiarities which correspond to those of the zodiacal light, and suggest the hypothesis that the light may be partly due to minute objects circulating in orbits like those of the smaller planets.

III.

On the Square Bar Micrometer.

By S. C. CHANDLER, Jr.

Communicated October 14, 1885.

1. The use of a square for the micrometric observation of comets was proposed in 1800, by D. Burckhardt, in Zach's *Monatliche Correspondenz*, Vol. I. p. 120. The idea had been suggested to him by a figure of such an instrument in Adam's "Description of Mathematical Instruments." Burckhardt shows the simple manner in which, by means of transits over the sides and the diagonal of the square, the difference of position of two objects can be determined, in any position of the square with reference to the diurnal motion, and its advantage over Bradley's rhomboidal micrometer in this respect. Nearly half a century later, the square was independently proposed by Mr. A. Graham, at the Markree observatory, and a very large use of it was made in the determination of approximate places of stars, for charting purposes. Graham constructs his micrometer by four flat bars of thin steel, laid over each other in the form of a square, and fastened by their projecting ends to a circular diaphragm. An improvement in the construction is to have a similar figure to that formed by the overlaid bars and the diaphragm cut out of a single plate of thin metal, so that all four sides lie in the same focal plane. Such a micrometer has been in use for about twenty years at the Harvard College observatory.

It seems singular that the square bar micrometer has not come into more general use. It appears to me to be preferable to the ring, having over the latter two important advantages, without compensating defects. First, all the transits may be observed over the following edges of the bars, so that the entries and exits are both determined by the phenomenon of *disappearance;* consequently the lengths of the observed chords are largely free from that highly prejudicial source of error, which is so troublesome in the ring micrometer, arising from the difference in estimating transits of such dissimilar objects as stars and comets, at disappearance and reappearance. An additional injurious effect of this cause proceeds, in the case of the ring, from the varying angle which the paths make with its edge.

A second advantage of the square is, that differences of right ascension and declination are observed with equal accuracy, irrespective of the difference of declination of the comet and the star, and of the parts of the micrometer which they traverse. In the ring micrometer, on the contrary, a considerable portion of its circumference cannot be used for declination determinations, and the difficulties which often arise from the inconvenient position of the comet relative to its comparison star, are such as require considerable skill and judgment to overcome, and render it a dangerous tool in the hands of an inexperienced observer.

In a third particular, of the least importance, the square recommends itself by the greater simplicity of the reductions. This advantage obtains fully, however, only when the equatorial is provided with a position-circle, and is in good adjustment; so that the same zero of position, once determined, will serve for observations in all parts of the sky. When the zero has to be determined at each observation, the labor involved fairly offsets this advantage.

From what experience I have had with both instruments I believe that the square bar micrometer may be advantageously substituted for the ring micrometer. As a means to bring it into wider employment, I have thought it would be useful to describe the processes of observation, and to develop the various formulæ of reduction, and this I proceed to do.

2. *Orientation of the square.* — The square is to be adjusted so that one diagonal is parallel either to the real, or to the apparent, diurnal motion. Which of these modes of orientation is adopted by the observer will depend upon his circumstances and instrument. The processes involved in this adjustment, and in the reduction of the observations, differ in the two cases in some important particulars. Their description is deferred for convenience to articles 9 and 10.

3. *Mode of observation, and notation of transits.* — The instants of transit to be noted are those of disappearance of the star or comet behind the edge of each bar. These transits will ordinarily be over those portions of the bars forming the sides of the square; but when the difference of declination is greater than the diagonal, it will be necessary to observe one or both objects over the prolongations of the bars beyond the square, north or south.

In order to deduce general formulæ, applicable without special modification to all observations, inside or outside the square, the following notation is adopted.

Call t_1 the time of the star's transit over the north following or the south following bar (i. e., the bars which intersect at the position angle 90°), whether the transit occurs inside or outside the square; and t_2 its time of transit over the north preceding or the south preceding bars (i. e., those intersecting at 270°), also irrespective of the place on the bar, inside or outside. Take for the comet the same letters accented, so that t'_1 and t'_2 are, respectively, the times of the comet's transit over a following and a preceding bar, as just defined, whether inside or outside. Thus t_2 is numerically greater than t_1, and t'_2 greater than t'_1, when the transit occurs inside, and less when it occurs outside. This notation preserves, algebraically, the relations which represent the geometric conditions for all the positions which the objects can occupy in the field, with reference to each other and to the square; and, if strictly adhered to, render all the formulæ hereafter given entirely general.

4. *Determination of the uncorrected apparent differences of right ascension and declination of two objects.*—By the term *uncorrected differences* are meant those found by assuming the micrometer to be perfectly adjusted, and the paths of the objects to be rectilinear, and also by ignoring the effects of refraction, and of the motion of the comet relative to the star during the observation.

Let α, α' be the apparent right ascensions, and δ, δ' the apparent declinations, of the star and comet, respectively; and let g be the value, in arc, of the diagonal of the square.

The uncorrected difference of right ascension will then be

$$\alpha' - \alpha = \tfrac{1}{2}(t'_1 + t'_2) - \tfrac{1}{2}(t_1 + t_2). \tag{1}$$

Calling d the difference of declination of the star and the centre of the square, we have

$$d = \pm \frac{g}{2} \mp \frac{t_2 - t_1}{2}\, 15 \cos \delta\,;$$

and, similarly for the comet, (2)

$$d' = \pm \frac{g'}{2} \mp \frac{t'_2 - t'_1}{2}\, 15 \cos \delta'\,;$$

where g and g' are of course numerically equal, but the upper or under sign is to be used, according as the path is north or south of the centre of the square. The difference of these equations gives

$$\delta' - \delta = d' - d = \pm \frac{g'}{2} \mp \frac{g}{2} - \frac{15}{2}\left[\pm (t'_2 - t'_1) \cos \delta' \mp (t_2 - t_1) \cos \delta\right], \tag{3}$$

which is the uncorrected difference of declination of the comet and the star. This general expression assumes the following forms for the special cases indicated below.

$$\left.\begin{array}{l}\text{Comet and star both north}\\ \text{Comet and star both south}\\ \text{Comet north, star south}\\ \text{Comet south, star north}\end{array}\right\} \delta' - \delta = \left\{\begin{array}{r} -\tfrac{15}{2}\left[(t'_2 - t'_1)\cos\delta' - (t_2 - t_1)\cos\delta\right]\\ +\tfrac{15}{2}\left[(t'_2 - t'_1)\cos\delta' - (t_2 - t_1)\cos\delta\right]\\ +g-\tfrac{15}{2}\left[(t'_2 - t'_1)\cos\delta' + (t_2 - t_1)\cos\delta\right]\\ -g+\tfrac{15}{2}\left[(t'_2 - t'_1)\cos\delta' + (t_2 - t_1)\cos\delta\right]\end{array}\right. \qquad (4)$$

For moderate declinations, say under 40°, we may take $\delta_0 = \frac{1}{2}(\delta' + \delta)$ and write equation (3) with sufficient practical accuracy

$$\delta' - \delta = d' - d = \pm\frac{g'}{2} \mp \frac{g}{2} - \frac{15}{2}\cos\delta_0\left[\pm(t'_2 - t'_1) \mp (t_2 - t_1)\right]; \qquad (5)$$

and the special forms (4) in a correspondingly simplified manner.

5. *Correction for curvature.*—When the declination of the objects observed is considerable, the difference of declination found by (3) requires a correction for the curvature of their paths, which may be obtained in the following manner:—

The value of d given by (2) corresponds to the distance from the centre of the square of the point of intersection of a great circle joining the places of the star's entry and exit, with the diagonal joining the north and south angles of the square. The actual path of the star, being a small circle, cuts the diagonal at a small distance, which we will call x, from the great circle. From the triangle formed by the pole, the star when on the bar, and the intersection of the great circle and diagonal, we have

$$\cot(\delta + x) = \cos\tfrac{15}{2}(t_2 - t_1)\cot\delta.$$

Developing this in the known way we find

$$x = \frac{\tan^2\frac{15}{4}(t_2 - t_1)}{\sin 1''}\sin 2\delta + \frac{1}{2}\,\frac{\tan^4\frac{15}{4}(t_2 - t_1)}{\sin 1''}\sin 4\delta + \ldots .$$

which is subtractive from the uncorrected value of d in (2). For the comet we have a precisely similar equation with accents. Hence, neglecting the 4th and higher powers, and employing the mean declination δ_0, we have, nearly, putting sines for tangents,

$$\delta' - \delta = (d' - d) - \frac{2\sin^2\frac{15}{4}(t'_2 - t'_1) - 2\sin^2\frac{15}{4}(t_2 - t_1)}{\sin 1''}\cos\delta_0\sin\delta_0,$$

where the last term is the required correction for curvature. If we take values m' and m from Table V., Chauvenet's Astronomy, Vol. II., using the side arguments $\frac{1}{2}(t'_2 - t'_1)$ and $\frac{1}{2}(t_2 - t_1)$, we can write this equation very simply,

$$\delta' - \delta = (d' - d) - (m' - m) \cos \delta_0 \sin \delta_0 ; \qquad (6)$$

where $(d' - d)$ is the uncorrected value given by (3). For a high declination we can, without sensible error, write $\cos \delta_0$ for $\cos \delta_0 \sin \delta_0$.

For very high declinations, say above 85°, we should, for greater accuracy in computing $(d' - d)$, substitute the sines for the arcs described by the star and comet; so that instead of (6) we have the more rigorous expression,

$$\delta' - \delta = \pm \frac{g'}{2} \mp \frac{g}{2} - \frac{\pm \sin \frac{15}{2} (t'_2 - t'_1) \cos \delta' \mp \sin \frac{15}{2} (t_2 - t_1) \cos \delta}{\sin 1''} - (m' - m) \cos \delta_0 . \qquad (7)$$

It will, however, seldom be necessary to employ this equation, since in practice, for stars so near the pole as to require it, the use of the square or of any micrometer dependent on transits, would be abandoned as inconvenient.

6. *Correction for proper motion.* — Let $\Delta \alpha'$ be the increase in time-seconds of the comet's right ascension, and $\Delta \delta'$ the increase in arc-seconds of its declination (positive for northerly motion), each during one sidereal second. It is manifest that the time of the comet's arrival at both preceding and following bars is accelerated or retarded by the amount necessary for it to describe an arc equal to the comet's motion in declination during half the duration of the transit. Consequently, to the uncorrected difference of right ascension given by (1) is to be added the correction

$$\pm \frac{t'_2 - t'_1}{2} \frac{\Delta \delta'}{15 \cos \delta'} ; \qquad (8)$$

where the upper or under sign is to be used, according as the comet passes north or south of the centre.

Another effect of the proper motion is to alter the length of the chord described in the interval $(t'_2 - t'_1)$ by an amount equal to the comet's motion in right ascension during that interval. The corrected length of the chord is $(t'_2 - t'_1)(1 - \Delta \alpha') \cos \delta'$, whence the uncorrected difference of declination found by (3) requires the correction

$$\pm \frac{t'_2 - t'_1}{2} \Delta \alpha' . 15 \cos \delta' ; \qquad (9)$$

the double sign having the same significance as before.

7. *Correction for refraction when the square is adjusted to the true diurnal motion.*—Let it be assumed that the square is oriented with reference to the true diurnal motion. Let θ be the sidereal time when the star is actually on the north and south diagonal, and $\Delta_1 \alpha$, $\Delta_2 \alpha$, the refraction in right ascension, and $\Delta_1 \delta$, $\Delta_2 \delta$, the refraction in declination, at entry and exit, respectively. Let the angular distance, expressed in time, of the middle points of the true and apparent paths from the diagonal be denoted by I and H, respectively. Then we have

$$\frac{t_2 + t_1}{2} - \theta = I \sec \delta = \frac{\Delta_2 \alpha + \Delta_1 \alpha}{2} - H \sec \delta.$$

It will be seen by consideration of the geometrical conditions that

$$H = \pm \frac{1}{15} \cdot \frac{\Delta_2 \delta - \Delta_1 \delta}{2},$$

the upper or under sign corresponding to positions north or south of the centre. Hence, since a similar equation obtains for the comet, with accents,

$$\frac{t_2 + t_1}{2} - \theta = \frac{\Delta_2 \alpha + \Delta_1 \alpha}{2} \mp \frac{1}{15} \cdot \frac{\Delta_2 \delta - \Delta_1 \delta}{2} \sec \delta,$$

$$\frac{t'_2 + t'_1}{2} - \theta' = \frac{\Delta_2 \alpha' + \Delta_1 \alpha'}{2} \mp \frac{1}{15} \cdot \frac{\Delta_2 \delta' - \Delta_1 \delta'}{2} \sec \delta'.$$

The difference of the first members gives

$$(\theta' - \theta) - [\tfrac{1}{2}(t'_2 + t'_1) - \tfrac{1}{2}(t_2 + t_1)].$$

The first term of this being the true difference of right ascension, and the second term the apparent difference (see equation (1)), we have manifestly from the difference of the second members of the above equations, the correction for differential refraction in right ascension,

$$\Delta(\alpha' - \alpha) = \tfrac{1}{2}[(\Delta_2 \alpha + \Delta_1 \alpha) - (\Delta_2 \alpha' + \Delta_1 \alpha')] + \tfrac{1}{2}[\pm(\Delta_2 \delta' - \Delta_1 \delta') \mp (\Delta_2 \delta - \Delta_1 \delta)] \frac{1}{15 \cos \delta_0}. \quad (10)$$

To get the effect of refraction on the difference of declinations, we observe that the length of the apparent path described by the star is

$$15 \cos(\delta) [(t_2 - t_1) - (\Delta_2 \alpha - \Delta_1 \alpha)],$$

where (δ) is the apparent[1] declination; and that, although not perpendicular to

---

[1] In this formula as originally written I had inserted the *true* declination. The manuscript having been transmitted to Professor Young, and carefully examined by his assistant, Mr. Malcolm McNeill, they kindly pointed out that, rigorously, the apparent declination should here be used. The effect of the difference is, of course, very small; in fact, inappreciable except for high declinations, near the horizon.

the diagonal, it will be equal in length, nearly, to a line drawn perpendicular to the diagonal at its intersection with the apparent path. Hence the distance of the middle point of the apparent path from the centre of the square will be

$$\pm \frac{g}{2} \mp \frac{15}{2} \cos(\delta) \left[(t_2 - t_1) - (\Delta_2 \alpha - \Delta_1 \alpha) \right];$$

and, since the distance between the apparent and true paths is $\frac{1}{2}(\Delta_2 \delta + \Delta_1 \delta)$, we have, putting $D =$ the declination of the centre,

$$\delta - D = \pm \frac{g}{2} \mp \frac{15}{2} \cos(\delta) \left[(t_2 - t_1) - (\Delta_2 \alpha - \Delta_1 \alpha) \right] - \tfrac{1}{2}(\Delta_2 \delta + \Delta_1 \delta).$$

Putting $(\delta) = \delta + \frac{1}{2}(\Delta_2 \delta + \Delta_1 \delta)$ and developing, neglecting squares of the refractions,

$$\delta - D = \pm \frac{g'}{2} \mp \frac{15}{2} \cos \delta \left[(t_2 - t_1) - (\Delta_2 \alpha - \Delta_1 \alpha) \right] - \tfrac{1}{2}(\Delta_2 \delta + \Delta_1 \delta)\left[1 \mp \tfrac{15}{2} \sin 1'' \sin \delta \, (t_2 - t_1)\right].$$

For the comet a similar equation obtains, with accents. Taking the difference and remembering the relation (3) we get $(\delta' - \delta) - (d' - d)$, or the correction for refraction in declination,

$$\begin{aligned} \Delta(\delta' - \delta) = {} & \tfrac{15}{2} \cos \delta_0 \left[\pm (\Delta_2 \alpha' - \Delta_1 \alpha') \mp (\Delta_2 \alpha - \Delta_1 \alpha) \right] - \tfrac{1}{2}\left[(\Delta_2 \delta' + \Delta_1 \delta') - (\Delta_2 \delta + \Delta_1 \delta) \right] \\ & + \tfrac{15}{2} \sin \delta \sin 1'' \left[\pm \frac{t'_2 - t'_1}{2} (\Delta_2 \delta' + \Delta_1 \delta') \mp \frac{t_2 - t_1}{2} (\Delta_2 \delta + \Delta_1 \delta) \right]. \qquad (11) \end{aligned}$$

It remains to reduce (10) and (11) to a form convenient for direct computation.

Assuming the refraction to vary at a uniform rate over the field of view, the first term of (10) is manifestly the difference of the refractions in right ascension for the star and the comet, at the middle points of their chords; and the second term is one half the difference between the changes in the refraction in declination for the comet and star, during the interval between their respective entries and exits, reduced to time at the given declination. Hence, if ζ and ζ' be the true zenith distances of the star and comet, and q and q' be their parallactic angles, we have (Chauvenet's Astronomy, Vol. II., equation 234),

$$\begin{aligned} & \tfrac{1}{2}(\Delta_2 \alpha + \Delta_1 \alpha) - \tfrac{1}{2}(\Delta_2 \alpha' + \Delta_1 \alpha') = k \frac{\tan \zeta \, \sin q}{15 \cos \delta} - k' \frac{\tan \zeta' \, \sin q'}{15 \cos \delta'}, \\ & \frac{1}{15 \cos \delta_0} \cdot \tfrac{1}{2}\left[\pm (\Delta_2 \delta' - \Delta_1 \delta') \mp (\Delta_2 \delta - \Delta_1 \delta) \right] = \qquad (12) \\ & \qquad \frac{1}{2 \cos \delta_0} \cdot \left[\mp (t'_2 - t'_1) \, k' \tan \zeta' \cos q' \pm (t_2 - t_1) \, k \tan \zeta \cos q \right]. \end{aligned}$$

Take a common value for ζ and q corresponding to the centre of the square, and Bessel's coefficient of differential refraction κ for this point. Put also, for brevity,

$$\mu = \frac{\tan\zeta \sin q}{\cos\delta}, \quad \nu = \tan\zeta \cos q. \tag{13}$$

Then the addition of (12) gives the value of (10), which may be written (on the general principle that, when u is a function of x, the change of u, corresponding to a small finite change $x' - x$, is $\frac{du}{dx}(x' - x)$),

$$\Delta(\alpha' - \alpha) = -\tfrac{1}{15}\kappa(\delta' - \delta)\frac{d\mu}{d\delta} - \kappa \sec\delta_0 \left[\pm\frac{t'_2 - t'_1}{2} \mp \frac{t_2 - t_1}{2}\right]\frac{d\nu}{d\alpha}. \tag{14}$$

The differential coefficients in (14) may be got from the known fundamental relations,

$$\begin{aligned} \cos\zeta &= \sin\phi \sin\delta + \cos\phi \cos\delta \cos t; \\ \sin\zeta \cos q &= \sin\phi \cos\delta - \cos\phi \sin\delta \cos t; \\ \sin\zeta \sin q &= \cos\phi \sin t. \end{aligned} \tag{15}$$

Differentiating these with respect to δ,

$$\begin{aligned} d(\cos\zeta) &= -\sin\zeta\, d\zeta = \sin\zeta \cos q\, d\delta; \\ d(\sin\zeta \cos q) &= -\cos\zeta\, d\delta; \\ d(\sin\zeta \sin q) &= 0; \end{aligned}$$

and substituting in the value of $\frac{d\mu}{d\delta}$ obtained from (13) we get

$$\frac{d\mu}{d\delta} = -\left[\tfrac{1}{2}\tan^2\zeta \sin 2q - \tan\zeta \sin q \tan\delta\right] \sec\delta. \tag{16}$$

Differentiating the first and second of (15) with reference to t,

$$\begin{aligned} d(\cos\zeta) &= -\sin\zeta\, d\zeta = -\sin\zeta \sin q \cos\delta\, dt; \\ d(\sin\zeta \cos q) &= \sin\zeta \sin q \sin\delta\, dt; \end{aligned}$$

and substituting in $\frac{d\nu}{dt}$ from (13), we get

$$\frac{d\nu}{dt} = \tfrac{1}{2}\tan^2\zeta \sin 2q \cos\delta + \tan\zeta \sin q \sin\delta. \tag{17}$$

Substituting (16) and (17) in (14), remembering that $d\alpha = -dt$ and also the relation (5), we derive, finally, the refraction correction in right ascension,

$$\Delta(\alpha'-\alpha)=\frac{\kappa}{15\cos\delta_0}\left(\pm\frac{g'}{2}\mp\frac{g}{2}\right)\left(\tfrac{1}{2}\tan^2\zeta\sin 2q+\tan\zeta\sin q\tan\delta\right)$$
$$-\frac{2\kappa}{15\cos\delta_0}(d'-d)\tan\zeta\sin q\tan\delta. \qquad (18)$$

To reduce the declination correction we note that the first term of (11) is equivalent to one half the difference between the changes in refraction in right ascension for the comet and star in the interval between entry and exit, reduced to arc of a great circle; while the second term is the difference of the refractions in declination, at the middle points of their chords. So that, in a similar way to that before used for (10), we transform the first two terms of (11) into

$$15\cos\delta\,\kappa\left(\mp\frac{t'_2-t'_1}{2}\pm\frac{t_2-t_1}{2}\right)\frac{d\mu}{d\alpha}-\kappa(\delta'-\delta)\frac{d\nu}{d\delta}.$$

With regard to the third term of (11), an examination shows that its numerical value must be very small, and that it may be expressed very nearly by

$$15\sin\delta\sin 1''\left[\pm\frac{t'_2-t'_1}{2}\mp\frac{t_2-t_1}{2}\right]\Delta\delta,$$

where $\Delta\delta$ is equal to the refraction in declination for a star at the centre of the field, and is expressed by $k\tan\zeta\cos q$; for which we may substitute without sensible error, κ cosec $1''\tan\zeta\cos q$, as is manifest from the way κ is derived from k. Therefore the third term of (11) may be written

$$15\cos\delta\,\kappa\left[\pm\frac{t'_2-t'_1}{2}\mp\frac{t_2-t_1}{2}\right]\nu\tan\delta.$$

Adding this to the above value of the first two terms of (11), and remembering that, from (5),

$$15\cos\delta\left[\pm\frac{t'_2-t'_1}{2}\mp\frac{t_2-t_1}{2}\right]=\pm\frac{g'}{2}\mp\frac{g}{2}-(\delta'-\delta),$$

we obtain

$$\Delta(\delta'-\delta)=\left[\pm\frac{g'}{2}\mp\frac{g}{2}-(\delta'-\delta)\right]\kappa\left(\nu\tan\delta-\frac{d\mu}{d\alpha}\right)-\kappa(\delta'-\delta)\frac{d\nu}{d\delta}. \qquad (19)$$

Differentiate the first and third of (15) with respect to t, and the second with respect to δ,

$$d(\cos\zeta)=-\sin\zeta\,d\zeta=-\cos\phi\cos\delta\sin t\,dt;$$
$$d(\sin\zeta\sin q)=\cos\phi\cos t\,dt;$$
$$d(\sin\zeta\cos q)=-\cos\zeta\,d\delta.$$

Also multiply the first of (15) by $\cos\delta$ and the second by $\sin\delta$, subtract and reduce, and we get

$$\frac{\cos\phi\cos t}{\cos\delta\ \cos\zeta} = 1 - \tan\zeta\cos q\tan\delta.$$

Employing these relations in the values of $\frac{d\mu}{dt}$ and $\frac{d\nu}{d\delta}$ from (13) we get,

$$\frac{d\mu}{d\alpha} = -\tan^2\zeta\sin^2 q + \tan\zeta\cos q\tan\delta - 1;$$

$$\frac{d\nu}{d\delta} = -1 - \tan^2\zeta\cos^2 q;$$

which, introduced into (19) give, finally, for the refraction correction in declination,

$$\Delta(\delta' - \delta) = \kappa\left(\pm\frac{g'}{2}\mp\frac{g}{2}\right)(\tan^2\zeta\sin^2 q + 1) + \kappa(d' - d)\tan^2\zeta\cos 2q. \qquad (20)$$

Equations (18) and (20) are, therefore, the expressions (general for any positions of the comet and star, inside or outside the square) by which the refraction corrections may be accurately computed, when the square has been oriented with respect to the *true* diurnal motion. We can often substitute for these the simpler approximate expressions, which involve the terms in $\tan^2\zeta$ only,

$$\left.\begin{aligned}\Delta(\alpha' - \alpha) &= \frac{\kappa}{30\cos\delta_0}\left(\pm\frac{g'}{2}\mp\frac{g}{2}\right)\tan^2\zeta\sin 2q;\\ \Delta(\delta' - \delta) &= \kappa\left(\pm\frac{g'}{2}\mp\frac{g}{2}\right)\tan^2\zeta\sin^2 q + \kappa(d' - d)\tan^2\zeta\cos 2q;\end{aligned}\right\} \qquad (21)$$

where, it will be noticed, the whole correction in right ascension, and the first term of that in declination, disappear when the star and the comet are observed in the same half of the square.

The precaution should always be exercised, before using the approximate values given by (21), to see, by a general inspection of the case in hand, whether the smaller terms of which the more rigorous equations (18) and (20) take account, are fairly negligible.

The constant κ can be computed from section C of Table II., in Vol. II. of Chauvenet's Astronomy, if necessary for the particular state of the air, by article 295, which also gives the formulæ for ζ and q. Except for extreme atmospheric conditions, or near the horizon, however, it will be sufficiently accurate to take $\log\kappa$ for the mean state of the air, or equal to $\log\alpha''$ of the table.

8. *Correction for refraction when the square is adjusted to the apparent diurnal motion.*—In this case the above formulæ for the right ascension, (18), or the first of (21), will require modification, on account of the effect of the difference in position angle between the true and the apparent motion. Call Δp the angle which the apparent path of a star, traversing the square, makes with its true path. This angle will be the ratio which the change in refraction in declination bears to the length of the chord, or

$$\Delta p = \frac{1}{15 \sin 1''} \cdot \frac{\Delta_2 \delta - \Delta_1 \delta}{\cos \delta \left[(t_2 - t_1) - (\Delta_2 \alpha - \Delta_1 \alpha) \right]}.$$

By the preceding article we find

$$\Delta_2 \delta - \Delta_1 \delta = 15 \kappa (t_2 - t_1) \frac{d \nu}{d t};$$

consequently we have, neglecting terms of the second order,

$$\Delta p = \frac{\kappa}{\sin 1''} \left[\tfrac{1}{2} \tan^2 \zeta \sin 2 q + \tan \zeta \sin q \tan \delta \right]. \tag{22}$$

Substituting this value for p in (25) we obtain

$$\frac{\kappa}{15 \cos \delta} \left[2 (d' - d) - \left(\pm \frac{g'}{2} \mp \frac{g}{2} \right) \right] \left(\tfrac{1}{2} \tan^2 \zeta \sin 2 q + \tan \zeta \sin q \tan \delta \right), \tag{22*}$$

as the correction to the difference of right ascension obtained by assuming the square to have been adjusted to the true diurnal motion. Adding (18) and (22*) we have

$$\Delta (\alpha' - \alpha) = \frac{\kappa}{15 \cos \delta_0} (d' - d) \tan^2 \zeta \sin 2 q, \tag{23}$$

which is the correction for refraction in right ascension when the square is oriented to the apparent diurnal motion, by the methods of article 10.

The declination correction is unaffected by the mode of adjustment.

It should be borne in mind that (23) has been deduced by assuming that the values of κ, ζ, and q are identical in (18) and (22); in other words, that the adjustment has been made with the telescope pointed in the same direction as for the comparisons of the comet and star. Ordinarily this assumption is nearly enough true; but near the horizon, for considerable hour angles, it may sometimes be requisite for accuracy to correct for refraction in right ascension by applying (18) and (22) separately, with the particular values of ζ and q pertaining to the comet comparisons and to the adjustment observations, respectively. With care, however, the necessity for this may almost always be avoided.

9. *Orientation of the square to the real diurnal motion.*— Suppose the telescope to be equatorially mounted, provided with a micrometer position circle, and in good adjustment, so that the instrumental pole is very close to the true pole, say within a minute of arc, as it should be in a well mounted instrument. Turn to a star on or very near the meridian, and set the square by the position circle so that the star traverses the diagonal, or parallel to it, as nearly as possible. Call the reading of the position circle P, and observe the times of transit as described in article 12. Since on the meridian Δp disappears, $p = p'$, and is found by equation (32). The reading $P - p$ will be the true zero of position at which the position circle should be thereafter set to orient the square to the true diurnal motion. If the equatorial is in good adjustment it will answer for all parts of the sky. If not, the correction due to the equatorial errors may be determined as shown in the text books (Chauvenet, II., p. 261).

If it be inconvenient to make this adjustment on the meridian, an extra-meridian determination can be made, the correction for refraction, Δp, being found by (22) and p' by (32). Then the reading for the setting to true diurnal motion will be $P - (p' + \Delta p)$.

It is scarcely necessary to say that the adapting tube and micrometer should be so marked, or fitted to each other, that the latter may always be inserted at a determinate position angle in the telescope.

If the telescope be not provided with a position circle the adjustment can still be made nearly as above described, with a little additional trouble, by several approximations, the tubes being carefully marked when the true position zero is found.

The refraction corrections to be used in reducing observations made with the square adjusted by this article are (18) and (20), or (21).

10. *Orientation of the square to the apparent diurnal motion.*— The adjustment by the previous article is to be preferred, on the score of convenience, when the micrometer is to be actively employed, as it need be made once only for all observations. Where, however, the telescope is not mounted equatorially, or the equatorial errors are unknown, or for other reasons, it may be necessary to adjust the square on the occasion of each observation. The orientation will then be more conveniently made with respect to the apparent diurnal motion. Several cases may arise.

Case I. Equatorial provided with position micrometer circle, instrumental adjustments unknown. Point the telescope as nearly as possible to the hour angle and zenith distance at which the comparisons of the comet and star are to be made immediately subsequent, and set the position circle so that a star will skirt along one side of the square, parallel to it. With several trials the position of parallelism can be approximated to quite closely. Then turn the position circle 45° and proceed with the comet comparisons. This, while not a refined method of observation, will answer well enough when the comet and its comparison star are nearly on a parallel; as the effect of an error in setting is then small.

Case II. For greater accuracy than the preceding method affords, when the difference of declination of the objects is considerable, or in the case there is no position circle, we can determine the error of setting as follows. Point the telescope as before, as nearly as possible in the direction in which the comet comparisons are to be made. Set the square by trial approximately so that a star will traverse the diagonal, or parallel to it. Observe the transit of a star as described in article 12, and deduce p' by equation (32). Then proceed with the comet observations, and in their reduction apply the correction computed by (25) or (26), putting p' for p.

Case III. A better way of proceeding is to arrange the observations so that p' can be determined simultaneously with $\alpha' - \alpha$, and $\delta' - \delta$. This method can be adopted, also, when the telescope is not mounted equatorially. If $\delta' - \delta$ is not much greater than the half diagonal, the comparisons of the comet and star may be so arranged that the latter passes near the centre and its transits observed as described in article 12. This will determine p' by (32), whence we get the correction for position zero by (25). If $\delta' - \delta$ is too great to allow this mode of observation, any star which traverses the central portion of the square during the comparisons, may be observed in conjunction with the comet and its comparison star, and p' thus determined.

The refraction corrections to be used in reducing observations made with the square adjusted by the methods of this article, are (23) for the difference of right ascensions, and (20), or the second of (21), for the difference of declinations.

11. *Correction for position zero.* — Let p expressed in arc be the small angle which the diagonal makes with the hour circle passing through the centre of the square, or the position angle of the north angle of the square. It is evident that the time when the star is on the diagonal is

$$\frac{t_2 + t_1}{2} - \frac{p \sin 1''}{15 \cos \delta} \left(\pm \frac{g}{2} - d \right),$$

and that to this must be added $\frac{p \sin 1''}{15 \cos \delta} d$, to get the time of crossing the hour circle passing through the centre of the square. Consequently the true difference of right ascension of a comet and star will be

$$\alpha' - \alpha = \tfrac{1}{2}(t'_2 + t'_1) - \tfrac{1}{2}(t_2 + t_1) + \frac{p \sin 1''}{15 \cos \delta}\left[2(d' - d) \mp \frac{g'}{2} \pm \frac{g}{2}\right]; \tag{24}$$

whence the correction to be added to the uncorrected difference of right ascension obtained by (1) is

$$\frac{p \sin 1''}{15 \cos \delta}\left[2(d' - d) - \left(\pm \frac{g'}{2} \mp \frac{g}{2}\right)\right] \tag{25}$$

or the equally convenient form

$$p \sin 1'' \left[\frac{\pm \frac{1}{2} g' \mp \frac{1}{2} g}{15 \cos \delta} \mp (t'_2 - t'_1) \pm (t_2 - t_1)\right]. \tag{26}$$

To get the accurate expression for the difference of declination it is to be noted that the distance from the angle of the square to the intersection of the star's path with the diagonal is $\pm \frac{g}{2} - d \sec p$; also that the triangle formed by the sides of the square and the star's path gives by Chauvenet's Trigonometry, equation (282),

$$\pm \frac{g}{2} - d \sec p = \pm (t_2 - t_1)\, 15 \cos \delta \sin (45^\circ + p) \sin (45^\circ - p);$$

whence

$$d = \pm \frac{g}{2} \cos p \mp \frac{t_2 - t_1}{2}\, 15 \cos \delta \frac{\cos 2p}{\cos p}, \tag{27}$$

the difference of which and a similar equation for the comet gives the accurate difference of declinations

$$\delta' - \delta = \left(\pm \frac{g'}{2} \mp \frac{g}{2}\right) \cos p - 15 \left[\pm \frac{t'_2 - t'_1}{2} \cos \delta' \mp \frac{t_2 - t_1}{2} \cos \delta\right] \frac{\cos 2p}{\cos p}. \tag{28}$$

This is a perfectly rigorous formula, whatever the value of p, and can be used in any position of the square, should occasion arise, provided neither object passes from the northern to the southern half of the square, or *vice versa*, during its transit. In general, however, p is small, and we can develop $\cos p$ and $\frac{\cos 2p}{\cos p}$ in series, neglecting 3d and higher powers. Thus we obtain the correction to be added to the result found by (3),

$$p^2 \sin^2 1'' \left[\frac{3}{2}\left(\pm \frac{t'_2 - t'_1}{2} \mp \frac{t_2 - t_1}{2}\right) 15 \cos \delta - \frac{1}{2}\left(\pm \frac{g'}{2} \mp \frac{g}{2}\right)\right], \tag{29}$$

or its equivalent,

$$p^2 \sin^2 1'' \left[\left(\pm \frac{t'_2 - t'_1}{2} \mp \frac{t_2 - t_1}{2}\right) 15 \cos \delta - \tfrac{1}{2}(d' - d)\right]. \tag{30}$$

This correction is in practice exceedingly small. Thus, for a square with 20 minutes of arc diagonal, and $p = 1^\circ$, the maximum value amounts to less than $0''.2$. The correction in declination on account of position zero may therefore, in general, be neglected.

12. *Determination of position zero.* — The angle p, as defined in article 11, is equivalent to the deviation of the diagonal lying on the parallel from the direction of the *true* diurnal motion; the angle p' is the deviation from the *apparent* motion; and Δp is the difference between the two, due to the refraction; so that

$$p = p' + \Delta p. \tag{31}$$

The value of Δp has been already given, equation (22); that of p' may be found by observation of a star over the central portions of the square, by noting the transits not only over the sides of the square, but also over the prolongations of the bars forming the sides at the preceding and following angles. Let t_0 and t_3 be the times of disappearance at the prolongation of the following and preceding bars, respectively, the notation for the transits over the sides being unchanged, or t_1 and t_2. Thus the order in which the four transits occur is t_0, t_1, t_2, t_3, over the following prolongation, the following side, the preceding side, and the preceding prolongation, respectively. Then it is obvious, without further explanation, that the value of p' will be given by

$$p' = \pm \frac{15 \cos \delta}{g \sin 1''} \left[\frac{t_3 + t_0}{2} - \frac{t_2 + t_1}{2} \right]; \tag{32}$$

the upper or under sign to be used, according as the transit is north or south of the centre.

13. *Determination of the diagonal of the square.* — The transits of a star whose declination is only approximately known, observed as described in the preceding article, will furnish the value of the diagonal. Thus the transits over the sides give, equation (27),

$$g = \pm \frac{2d}{\cos p} + (t_2 - t_1)\, 15 \cos \delta \, \frac{\cos 2p}{\cos^2 p},$$

and the transits over the prolongations,

$$g = \mp \frac{2d}{\cos p} + (t_3 - t_0)\, 15 \cos \delta \, \frac{\cos 2p}{\cos^2 p};$$

from the sum of which we derive

$$g = [(t_3 - t_0) + (t_2 - t_1)]\, \tfrac{15}{2} \cos \delta - g\, p^2 \sin^2 1'', \tag{33}$$

which is the apparent value of the diagonal, as affected by the refraction. The term in p^2 is inappreciable for small values of p. When it cannot be neglected it can be determined by means of (32).

The apparent value of g found from (33) may be freed from refraction by applying the correction

$$\Delta g = - g \kappa (\tan^2 \zeta \sin^2 q - \tan \zeta \cos q \tan \delta + 1). \tag{34}$$

If the observations for determining the diagonal are made upon equatorial stars, in the meridian, the refraction correction reduces to

$$\Delta g = - g \kappa, \tag{35}$$

and can thus be allowed for in a very simple manner. The diagonal may also be found by means of pairs of stars whose differences of declination are accurately known, by means of the relation (3), or, for the highest precision, (28), employing the apparent differences of declination. As this method possesses no advantages over that above presented, and the procedure is obvious, it is not worth while to give details.

14. *Deformation of the square.* — In what has preceded it has been assumed that the micrometer is a perfect square. It should be tested in this respect either by measurement, or by observation of transits of equatorial stars near the meridian. Thus any perceptible inequality of the diagonals can be ascertained by the preceding article, while the equality of the sides may be certified by placing each in succession parallel to the diurnal motion, and observing transits across the adjacent sides near its intersection with them.

If the square has been carefully constructed the errors should be very small. The effect of any tendency to rectangular or rhomboidal form will be eliminated from observed differences of right ascensions and declination, if the comparisons are taken with the square placed first with one, and then with the other diagonal, parallel to the diurnal motion, an equal number of comparisons in each position.

15. *Numerical illustrations.* — In the following examples of the application of the preceding formulæ, some of the corrections are very small and, in practice, would be neglected, but are here computed for illustration.

Example I. — Great comet 1881, III., observed at Harvard College observatory ($\phi = 42° 22'.8$), June 29, 1881. Square assumed adjusted to *true* diurnal motion. Diagonal, $889''.8$. Approximate $\delta = 66° 10'.5$, $\delta' = 66° 1'.5$. $\zeta = 67° 42'$, $q = + 29°.2$. Comet's motion in a second, $+ 0^s.0049$, and $+ 0''.101$.

OBSERVED TRANSITS.

Comparison.	Comet South.		Star North.	
	t'_1.	t'_2.	t_1.	t_2.
	h. m. s.	m. s.	m. s.	m. s.
1	15 45 20.3	46 11.1	42 58.2	43 50.3
2	49 16.9	50 17.2	46 59.1	47 49.7
3	53 17.0	54 26.4	51 2.6	51 52.5
4	57 53.0	59 13.1	55 43.4	56 32.2

REDUCTION; EQUATION (1) AND FOURTH OF EQUATION (4).

Comp.	$\frac{t'_1+t'_2}{2}$.	$\frac{t_1+t_2}{2}$.	$\alpha'-\alpha$.	$t'_2-t'_1$.	t_2-t_1.	
	h. m. s.	m. s.	m. s.	s.	s.	
1	15 45 45.70	43 24.25	+ 2 21.45	50.8	52.1	
2	49 47.05	47 24.40	22.65	60.3	50.6	
3	53 51.70	51 27.55	24.15	69.4	49.9	
4	58 33.05	56 7.80	25.25	80.1	48.8	
Sid. chron.	15 51 59.38 ;		+ 2 23.38	65.15	50.35	
Chron. corr.	− 16 48.7		log (t_2-t_1)	1.81391	1.70200	
Sid. time,	15 35 10.7		log $\frac{15}{2}$	0.87506	0.87506	
Reduction,	6 33 5.0		log cos δ	9.60889	9.60632	
				2.29786	2.18338	
				+ 198.55	+ 152.54	= + 351.09
						− 889.80
Cam. M. T.	$9^{h}\ 2^{m}\ 5^{s}.7$;		$\alpha'-\alpha = +2^{m}\ 23^{s}.38$;	$\delta'-\delta = -8'\ 58''.71$		= − 538.71

REFRACTION CORRECTION.

CONSTANTS.

log $(-g)$	n 2.949	log tan ζ	0.387
log $(d'-d)$	n 2.732	log $\tan^2\zeta$	0.774
log cos δ_0	9.608	log sin q	9.686
log tan δ_0	0.353	log sin $2q$	9.930
log κ	6.435	log cos $2q$	9.719

Right Ascension Correction, Equation (18).

$\frac{1}{2}\tan^2\zeta\sin 2q$	$+2.53$	0.403
$\tan\zeta\sin q\tan\delta$	$+2.67$	0.426
	$+5.20$	0.716
$-g\kappa$		$n\,9.384$
a. c. $(15\cos\delta)$		9.216
1st term	-0.207	$n\,9.316$
$\tan\zeta\sin q\tan\delta$		0.426
$-2\kappa(d'-d)$		9.468
a. c. $(15\cos\delta)$		9.216
2d term	$+0.129$	9.110
$\Delta(\alpha'-\alpha)$	$-0^{s}.078$	

Declination Correction, Equation (20).

$\tan^2\sin^2 q$	$+1.40$	0.146
	$+1.00$	
	$+2.40$	0.380
$-g\kappa$		$n\,9.384$
1st term	-0.58	$n\,9.764$
$\tan^2\zeta\cos 2q$		0.493
$\kappa(d'-d)$		$n\,9.167$
2d term	-0.46	$n\,9.660$
$\Delta(\delta'-\delta)$	$-1''.04$	

Curvature Correction, Equation (6).

$\frac{1}{2}(t'_2-t'_1) = 32^{s}.6$: table V. gives $m' = 0''.58$

$\frac{1}{2}(t_2-t_1) = 25.2$: table V. gives $m = 0.34$

$\cos\delta\sin\delta = 0.37 \times$ $m'-m = 0.24$

Correction $= -0''.09$.

Proper Motion Correction, Equations (8) and (9).

$\Delta\alpha'$	$+.0049$	7.690
$\Delta\delta'$	$.101$	9.004
$-\frac{1}{2}(t'_2-t'_1)$	32.6	1.513
$15\cos\delta$		0.784
Corr. in α	$-0^{s}.54$	$n\,9.733$
Corr. in δ	$-0''.97$	$n\,9.987$

Summary.

	$\alpha'-\alpha$.	$\delta'-\delta$.
	m. s.	′ ″
Uncorrected	$+2$ 23.38	-8 58.71
Refraction	$-$ 0.08	$-$ 1.04
Curvature	—	$-$ 0.09
Motion	$-$ 0.54	$-$ 0.97
Corrected	$+2$ 22.76	-9 0.81

Example II.—Barnard's comet, 1885 II., observed at Harvard College observatory ($\phi = 42^\circ\ 22'.8$), July 12, 1885. Square adjusted to apparent motion as by case III. of article 10. Diagonal, $884''.0$. $\delta_0 = -7^\circ\ 42'.1$.

OBSERVED TRANSITS. (See article 12.)

Comparison.	Comet North.		Star North.			
	t'_1.	t'_2.	t_0.	t_1.	t_2.	t_3.
	h. m. s.	m. s.	m s.	m. s.	m. s.	m. s.
1	16 47 28.0	47 38.6	45 42.5	45 51.2	46 42.0	46 50.5
2	50 57.5	51 8.0	49 12.4	49 21.2	50 12.0	50 20.6
3	55 25.0	55 35.3	53 39.2	53 48.7	54 38.7	54 48.0
4	59 23.4	59 35.0	57 38.5	57 48.5	58 37.9	58 47.5
5	17 4 30.2	4 46.3	2 50.2	2 56.1	3 49.5	3 55.5
6	7 59.6	8 15.5	6 20.0	6 26.2	7 20.6	7 25.5

REDUCTION.

Comparison.	$\frac{1}{2}(t'_2+t'_1)$.	$\frac{1}{2}(t_2+t_1)$.	$\alpha'-\alpha$.	$t'_2-t'_1$.	t_2-t_1.	Diff.
	h. m. s.	m. s.	m. s.	s.	s.	s.
1	16 47 33.30	46 16.60	+1 16.70	10.6	50.8	−40.2
2	51 2.75	49 46.60	16.15	10.5	50.8	40.3
3	55 30.15	54 13.70	16.45	10.3	50.0	39.7
4	59 29.20	58 13.20	16.00	11.6	49.4	37.8
5	17 4 38.25	3 22.80	15.45	16.1	53.4	37.3
6	8 7.55	6 53.40	14.15	15.9	54.4	38.5
Mean	16 57 43.54	56 27.72	+1 15.82	12.50	51.47	−38.97
				log		n 1.59073
Chron. corr.	−28.0	Corr. for p'	−0.12	$\log(-\frac{15}{2})$		n 0.87506
Sid. time	16 57 15.5	(See p. 177.)		$\cos\delta_0$		9.99606
Red.	7 24 35					2.46185
Cam. M. T.	= 9 32 40	$\alpha'-\alpha=$	+1 15.70	$\delta'-\delta=$		+4′ 49.63

The above is a convenient form of reduction. Its three lower sections contain the determination of the local mean time of observation; the difference of right ascension, equation (1), corrected for position zero, determined on p. 177; and the difference of declination determined by (5), the declination being small.

CORRECTION FOR POSITION ZERO, EQUATIONS (32) AND (26).

$\frac{t_3+t_0}{2}$	$\frac{t_3+t_0}{2}-\frac{t_2+t_1}{2}$
m. s.	s.
46 16.50	−0.10
49 46.50	−0.10
54 13.60	−0.10
58 13.00	−0.20
3 22.85	+0.05
6 52.75	−0.65
	−0.18

Equation (32)	$\log(-0^s.18)$	$n\,9.2553$
	$15\cos\delta$	1.1721
		$n\,0.4274$
	g	2.9465
	$p'\sin 1''$	$n\,7.4809$
Equation (26)	$\log(38.97)$	1.5907
		$n\,9.0716$
	Corr. of $(\alpha'-\alpha)$	$-0^s.12$

applied on p. 176.

From Chauvenet's Astronomy, II., equation (348), $\zeta = 50^\circ\ 12'$, $q = -3^\circ\ 32'$. Then

$\log\kappa$	6.443	$\log\sin q$	$n\,8.790$
$\log\tan\zeta$	0.079	$\log\cos q$	9.999
$\log\tan^2\zeta$	0.158	$\log\sin 2q$	$n\,9.090$
$\log\cos\delta$	9.996	$\log\cos 2q$	9.997
$\log\tan\delta$	$n\,9.131$		

REFRACTION CORRECTION.

IN RIGHT ASCENSION, EQUATION (23).

$\tan^2\zeta\sin 2q$		$n\,9.248$
$\kappa(d'-d)$		8.905
a. c. $(15\cos\delta)$		8.828
$\Delta(\alpha'-\alpha)$	$-0^s.001$	$n\,6.981$

IN DECLINATION, EQUATION (20).

$\tan^2\zeta\cos 2q$	$+1.43$	0.155
$\kappa(d'-d)$		8.905
$\Delta(\delta'-\delta)$	$+0''.11$	9.060

It can be seen by inspection that, on account of small declination and moderate motion, the corrections for curvature and proper motions must be insignificant; also, that the refraction correction must be very small; the latter is computed, however, to illustrate the special formula (23) for the case of adjustment to apparent motion.

VALUE OF DIAGONAL, EQUATIONS (33) AND (35).

t_3-t_0.	t_2-t_1.	Sum.
s.	s.	s.
68.0	50.8	118.8
68.2	50.8	119.0
68.8	50.0	118.8
69.0	49.4	118.4
65.5	53.4	118.9
65.5	54.4	119.9
67.50	51.47	118.97

Equation (33)	$\log(118.97)$		2.07544
	$\frac{15}{2}\cos\delta$		0.87112
		$884''.22$	2.94656
	$-g\,p^2\sin 1''$	-0.01	
Equation (35)	$-g\kappa$	-0.24	
	g	$= 883.97$	

MEMOIRS

OF

THE AMERICAN ACADEMY

OF

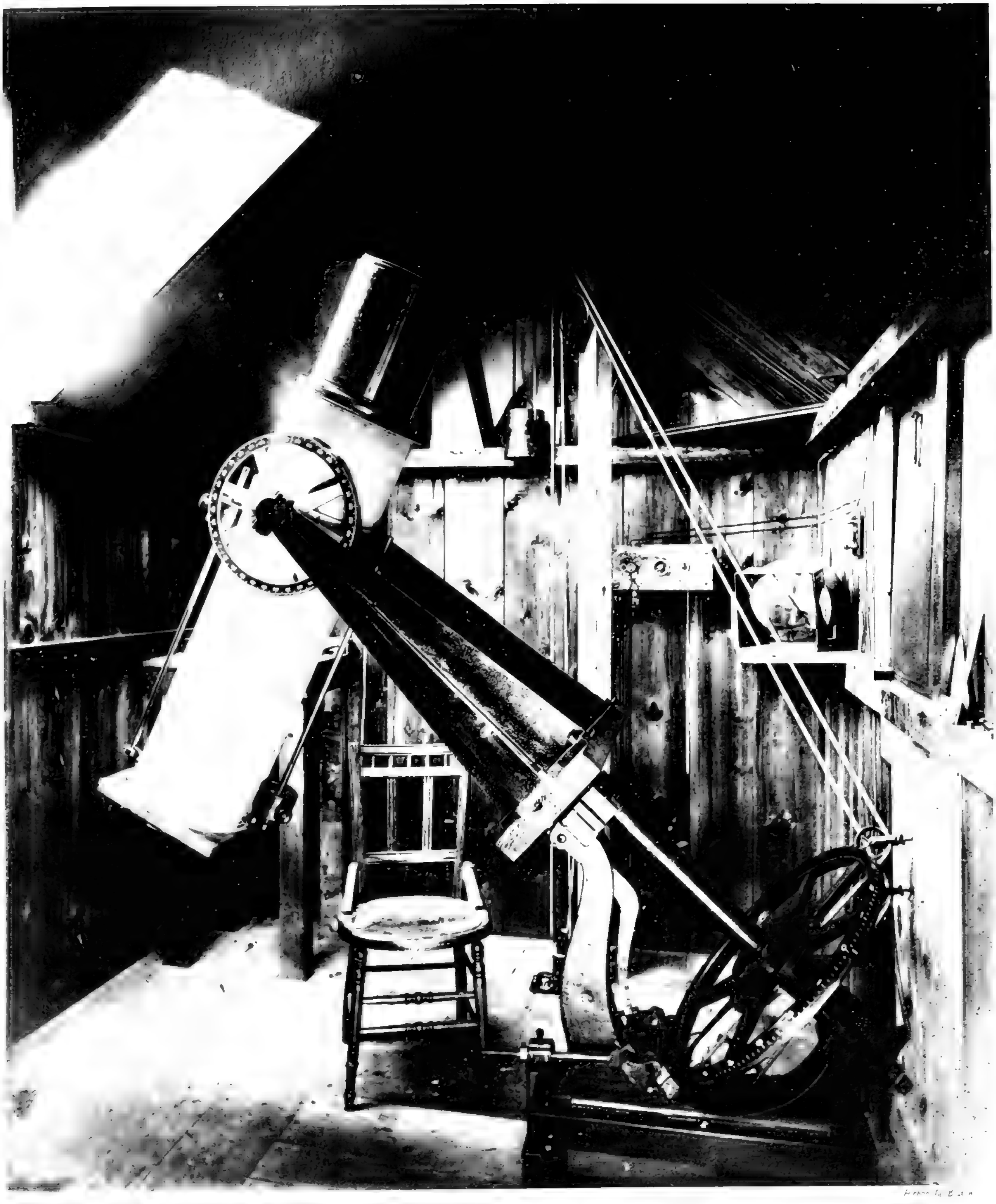
ARTS AND SCIENCES.

MDCCLXXX.

CENTENNIAL VOLUME.

Vol. XI.—Part IV.—No. IV.

CAMBRIDGE:
JOHN WILSON AND SON.
University Press.
1886.



Forbes Co. Boston

Plate 1

— PHOTOGRAPHIC TELESCOPE. —

[Investigations on Light and Heat published with Appropriation from the Rumford Fund.]

IV.

Stellar Photography.

By EDWARD C. PICKERING.

Presented March 10, 1886.

The experiments to be described below were mainly conducted by the aid of an appropriation made in June, 1885, from the Bache Fund of the National Academy of Sciences. Numerous preliminary experiments had been made with a grant from the Rumford Fund of the American Academy. My attention was directed to stellar photography in 1882, by Mr. W. H. Pickering. Many of the preliminary experiments were made by him, and his advice was followed regarding the photographic processes to be employed. In the later work, he has rendered important aid by his advice, and by making many auxiliary experiments in his photographic laboratory at the Massachusetts Institute of Technology. The actual exposures and development of the photographs have been made by several assistants in turn. From June 11, 1885, to October 16, 1885, this work was intrusted to Mr. A. H. Whittemore; from October 17, 1885, to January 26, 1886, to Mr. H. Helm Clayton; and from February 2, 1886, to the present time, to Mr. Willard P. Gerrish. To the skill and perseverance shown by these gentlemen the success attained is largely due.

The following subjects are discussed below in turn:—

History of Stellar Photography.
Preliminary Experiments, 1882 to 1885.
Description of the Photographic Apparatus finally adopted.
Theoretical Considerations entering into the Problem of Stellar Photography.
Trails formed by Stars when their apparent Motion is not wholly corrected by the Motion of the Telescope.
Construction of Charts by Photography.
Stellar Spectra.
Brighter Stars in the Pleiades.
Close Polar Stars.

HISTORY.

Stellar photography originated in an experiment made at the Harvard College Observatory on July 17, 1850. Under the direction of Professor W. C. Bond, Mr. J. A. Whipple placed a sensitive daguerreotype plate in the focus of the fifteen-inch equatorial, which by means of its driving-clock was kept pointed upon the star α *Lyræ*. A satisfactory image of the star was thus obtained. Subsequently, the double star α *Geminorum* gave an elongated image, evidently due to its two components. Objects as bright as these gave but faint images, and no impression was obtained from the Pole-star, however long the exposure continued. The experiment was repeated with various stars and clusters, but the work was finally abandoned owing to the imperfections of the driving-clock and the lack of sensitiveness of the plates (Harvard Observatory Annals, I. cxlix, clvii, clxv). Both of these difficulties were partially remedied in 1857, and the research was resumed by Professor G. P. Bond. The driving-clock, regulated by a conical pendulum, was replaced by a larger clock, controlled by a Bond's spring-governor. The introduction of the collodion process had greatly reduced the photographic difficulties, and furnished plates of much greater sensitiveness. The results of this investigation are contained in three important papers, which were published in the Astronomische Nachrichten, XLVII. 1, XLVIII. 1, and XLIX. 81, and have now become classical. The first of these papers states that on April 27, 1857, an impression of the double star ζ *Ursæ Majoris* was obtained in eight seconds. An exposure of two or three seconds was afterwards found to be sufficient to produce an impression of the brighter star; and when the telescope was at rest, a trail was obtained as the image of the star α *Lyræ* traversed the plate. A series of measures was made of the position angle and distance of the companion of ζ *Ursæ Majoris*. The probable error of a single photographic distance was found to be $\pm 0''.12$. The faintest star photographed was the companion of ε *Lyræ*, which has a magnitude of 6.0. The second paper contains a careful study of the distance of the components of ζ *Ursæ Majoris*. The result was $14''.21 \pm 0''.013$ from measures of sixty-two images taken on eight nights. The extreme variations in the results of these eight nights was only $0''.08$, and the probable error of a single measure was $\pm 0''.05$. The third paper is devoted to a discussion of the relative brightness of the stars as indicated by the diameters of the photographic images. The advantages of photography as a means of locating the stars in a cluster are clearly stated. In fact, nearly all the arguments now offered in favor of photography will be found in these admirable papers.

These experiments were soon after repeated by Mr. De la Rue and by Mr. Rutherfurd. A much more extended investigation was undertaken in 1864 by Mr. Rutherfurd, and continued by him during many years. A brief notice of this work was published in the American Journal, XXXIX., 1865, 304. One of his photographs of the *Pleiades* was measured and discussed by Dr. B. A. Gould, in 1866, in the Astronomische Nachrichten, LXVIII. 184. A list of the clusters photographed by Mr. Rutherfurd is given by Professor Holden, in the Smithsonian Miscellaneous Collections, 311, page 89. The faintest stars shown in these photographs are probably not far from the ninth magnitude. By the continued improvement in photographic processes, each experimenter after a few years has a great advantage over his predecessors. The invention of dry plates simplified the work of taking a photograph, permitted an indefinite prolongation of the time of exposure, and ultimately greatly increased the sensitiveness of the film. Aided by these advantages, Dr. Henry Draper attacked the problem with his usual skill and perseverance. On March 11, 1881, he obtained a photograph of the Nebula of Orion, in which a star is shown whose photometric magnitude is about 14.7. This star is barely visible with a telescope of the same aperture as that with which the photograph was taken. The photographic plate, accordingly, had now become as efficient an instrument of research as the eye itself, by means of its power of accumulating the energy radiated upon it. For a further discussion of the faintest stars thus photographed, see Washington Observations, 1878, page 226, and Proceedings of the American Academy, XX. 407. But for Dr. Draper's untimely death, he would doubtless have been the first to accomplish the striking experiment of photographing a star too faint to be seen in the largest telescopes. This result was apparently soon after attained by Mr. A. A. Common, in his beautiful photograph of the Nebula of Orion. It is not safe to draw conclusions from a single star, on account of the effect of color. A red and a blue star may produce photographic images of equal intensity, although to the eye their brightness may differ by several magnitudes. A comparison of the photograph of Mr. Common with the catalogue of Bond (Annals Harvard College Observatory, V. 270) has been made by the writer (Proc. Amer. Acad., XX. 407). From this it appears that the number of stars contained in the photograph and not given in the catalogue is about equal to the number of stars in the catalogue which are wanting in the photograph. We may therefore conclude that the limiting magnitude for the photograph does not differ greatly from that of the faintest stars visible to the eye. The largest telescopes add but few stars to those given by Bond, although this nebula has been thoroughly scrutinized with the reflectors of the

Earl of Rosse and the Washington refractor. An important part of the work of Dr. Gould at the Cordoba Observatory consisted in securing photographs of the principal clusters in the southern hemisphere, but the results have not yet been published.

During the past three or four years, stellar photography has been pursued at various observatories. Dr. Gill has undertaken to make a map of the southern heavens by photography. A catalogue of five hundred stars, whose light was determined from their photographs, was published by the Rev. T. E. Espin in the Proceedings of the Liverpool Astronomical Society, Transactions, No. 3, 1884. The most elaborate investigation is that of the MM. Henry, of the Paris Observatory. Admirable photographic maps of the stars have been constructed with the intention of substituting them for the charts of Peters and Chacornac. It is impossible, however, to make a statement of the photographic work in progress at the present time, on account of the rapid advances now being made in this department of astronomy.

In 1863, Dr. Huggins obtained a photographic image of the spectrum of Sirius, but it was so ill-defined that it presented no indications of lines. (Phil. Trans., 1864, p. 428.) The first successful photograph of the spectrum of a star was obtained by Dr. Henry Draper, in 1872. A spectrum of Vega was taken, in which four lines were visible. (Amer. Jour. Sci., 1879, XVIII.) The work was afterwards resumed by each of these astronomers, but was confined to the brightest stars. (Proc. Amer. Acad., XIX. 231; Phil. Trans., 1880, p. 669.) The method employed was the same in both cases, and consisted in concentrating the light of the star by means of a large telescope upon the slit of a spectroscope placed in its focus. A narrow slit was necessary to secure good definition, and very perfect adjustment of the telescope was required to keep the image of the star upon the slit.

PRELIMINARY EXPERIMENTS.

A great variety of preliminary experiments were made in connection with this research, by the aid of an appropriation from the Rumford Fund. In 1882, a photographic lens having an aperture of 7 inches and a focal length of 37 inches was procured, and attached to the equatorial mounting in the west dome of the Harvard College Observatory. Afterwards the camera containing this lens was mounted in the meridian and directed towards the equator. The plate-holder was attached to a car, which was drawn by clockwork at the rate of 0.16 in. per minute from west to east. If the plate was at rest, each star in turn, as it approached the meridian, would form an image on the western edge of the plate, gradually traversing it along a horizontal line. The velocity would be proportional to the focal length, and in this case would be 0.16 in. per minute. If then the plate was moving with the same velocity in the same direction, the star would evidently form a circular dot upon it. A panoramic photograph was thus taken, and the region covered was only limited by the length of the plate. It was proposed to expose in this way a series of plates, one following the other, and thus photograph zones several hours in length. On December 6, 1882, the first photograph was taken by this method. On one plate 462 stars were counted where only 55 occur in the Uranometria Argentina. The faintest stars were probably of about the ninth magnitude. The images were large and distorted, owing to defects of the lens and to imperfect adjustment of the apparatus. Otherwise, much fainter stars would have been photographed. For zones in other declinations a conical motion could be given to the car by means of a series of curved tracks, or by other devices. On February 21, 1883, a photograph of Orion was obtained by Mr. W. H. Pickering with a small Voigtländer camera and without clockwork. Although the aperture was only 1.6 in. and the focus 5.2 in., trails were obtained of stars as faint as the fifth magnitude. Still better results were obtained with a Voigtländer No. 4 lens (Series B), having an aperture of 2 inches and a focal length of 7 inches.

Attaching clockwork and giving an exposure of thirty minutes, a photograph was obtained of all the stars down to the eighth magnitude in a region about 15° square. Plans were prepared for photographing a large part of the sky in this way. The lens was mounted equatorially with a long rod attached to the declination axis. A ribbon of brass was fastened to the end of the rod, and by clockwork was wound uniformly around a drum. A second series of photographs was undertaken with this same instrument. Six portions of the plate could be brought in turn to the focus of the lens, and three exposures were to be made on each part of the plate. No clockwork was to be used, and the different regions taken on the same part of the plate were to be distinguished by the length of the trails. This was accomplished by giving to the various regions a single exposure, a long exposure followed by a short one, or a short exposure followed by a long one. In order to direct the telescope quickly to the desired portion of the sky, notches were made in both declination and right ascension circles at intervals of 15°. To reduce the results to a scale of stellar magnitudes, trails were taken with a series of apertures, whose area formed a measure of the light transmitted. Another method which is also applicable when clockwork is used, consists in attaching a prism of very small angle to the centre of the object-glass. The portion of the light falling upon this will form a companion to each star. The ratio of the true brightness of the star to that of its companion is a constant quantity, and is readily determined from the absorption of the prism and the ratio of its area to that of the uncovered portion of the lens. If the stars and companions are then measured upon any empirical scale, this ratio of light serves to reduce the results to absolute measures.

To remedy the variation arising from the color of the stars, an attempt was made to render the light monochromatic. One method proposed for this purpose consisted in using as an object-glass an uncorrected lens. The focus of this varies very greatly with the color of the light. The rays out of focus would be spread over so large a circle that they would have but little effect upon the image. By covering the centre of the lens by a diaphragm, or by a prism of small angle, the light at the centre of the image of the star would be nearly monochromatic. By taking a series of plates with various foci, the relative intensity of the light of each different color could be determined. The most important of these methods, and the results attained by them, were described and exhibited to the Royal Astronomical Society at their meeting on June 8, 1883. (Observatory, VII. 199; Astron. Register, XXI. 149.)

Photographic Apparatus.

A second series of experiments was undertaken in March, 1885, with results that seemed to justify their repetition on a larger scale. An application was accordingly made to the Board of Directors of the Bache Fund, and an appropriation was granted by means of which the following work was accomplished. A Voigtländer lens having an aperture of 8 inches and a focal length of about 45 inches was obtained, and intrusted to Messrs. Alvan Clark and Sons for correction and mounting. Errors which are quite inappreciable in ordinary photographic work may be large enough to ruin a stellar photograph. This was found to be the case with the lens mentioned above. It was also desirable that its focal length should be 114.6 cm., so that the scale of the photographs should be as nearly as possible 2 cm. to 1°, which is the scale of the maps of the Durchmusterung. These difficulties were finally overcome, but it was necessary to regrind two of the glass surfaces. The lens was next mounted equatorially, as is shown in Plate I. The brass tube carrying the lens is screwed into the end of a steel tube which is mounted in trunnions at the ends of a large fork. This fork forms the prolongation of the polar axis, and possesses some important advantages over the usual equatorial mounting. It is much lighter than the German form in common use, since the tube is not eccentric, and therefore no counterpoise is required. It does not have to be reversed when a star crosses the meridian, and in fact any star may be followed uninterruptedly from rising to setting. The advantage over the English form of mounting is, that polar stars can be observed without difficulty. The objection to its general introduction is, that the end of the polar axis would interfere with observations made near the pole. A declination circle is attached to the tube and divided into single degrees. A closer division is not necessary, since a small error in setting would only affect the part of the plate on which a star would impress itself. Notches are cut in the edges of the circle for each degree, every tenth notch being made deeper than the others. A catch at the end of a steel spring is attached to the fork, and enables the telescope to be moved quickly and with precision either 1° or 10° at a time, as may be desired. The edges of the catch are ground at a greater angle than that of friction, and thus permit the telescope to be moved when sufficient pressure is applied. The right ascension circle consists of an iron wheel 67 cm. in diameter, in the edges of which 720 teeth are cut with great care. A screw turns in these teeth, forming a worm and wheel. One tooth corresponds to half a degree, or to two minutes of time in right ascension. An index serves to set the telescope within a minute or less, and this is close enough for the present purpose. The screw is driven by clockwork controlled by a Bond spring-governor, the weights being connected by the Huyghenian arrangement, so that they may be rewound without stopping the clockwork. It is difficult to make a pendulum keep accurate time in a location where the variations in temperature are great. Moreover, to photograph the fainter stars it is necessary that the clockwork should run for a long time with a high degree of accuracy. These conditions are fulfilled by controlling the Bond spring-governor electrically by a clock mounted in the clock-room of the Observatory. If the polar axis is parallel to the axis of the earth, the telescope can thus be made to follow a star for an indefinite time, as closely as the clock can be made to run. The error from this source is therefore entirely inappreciable. The differential refraction of the air would be a more serious source of error than this. The electrical contacts occurred in the clock every two seconds, and that corresponding to the fifty-eighth second was omitted. A spring-governor will run more satisfactorily when the contact occurs every second, or oftener; but with the present arrangement the error could seldom exceed a fraction of a second. The fifty-eighth second was omitted by a secondary connection in the clock occurring once a minute, and not, as is sometimes done, by the omission of one tooth in a contact wheel. The removal of the secondary connection gave the signals uninterruptedly. Finally, the clock was arranged as a make-circuit and the governor required a break-circuit. This difficulty was remedied by throwing the clock out of the circuit and using it as a shunt to the battery. The circuit was thus closed both through the clock and the governor. The clock resistance was so small that but little of the current ordinarily passed through the governor. Every two seconds the clock circuit was broken, and the entire current passed through the governor. An incidental advantage of this arrangement is, that, as the circuit is never entirely broken, no spark occurs within the clock.

The frame carrying the polar axis rested on a bed-plate with adjusting screws so that it could be raised or lowered at either corner or moved in azimuth. The whole rested on a large stone imbedded in the ground and covered by a transit shed, which had been constructed for observing the Transit of Mercury in 1878. All the photographs were taken near the meridian, where the atmospheric absorption and refraction are least and vary most slowly. The stone did not prove to be sufficiently immovable when subjected to frosts and thaws, and consequently a circular level was attached to the frame of the instrument. The polar axis could thus always be brought back to the same altitude, whatever the motion of the stone.

The transit shed covering the instrument originally had a slit only one foot in width. This was widened to two feet and closed by two light shutters covered with canvas. It was expected that this would permit stars on the equator to be reached when one hour east or west of the meridian. When the instrument was mounted, the axis was found to be lower than had been anticipated, and the edges of the slit began to interfere when the telescope was no more than twenty minutes from the meridian. This difficulty was remedied in March, 1886, when the instrument was remounted. It was then placed on the pier used during the Transit of Mercury, which proved a much steadier support. It also permitted exposures of over an hour on the equator, and longer exposures near the pole, without interfering with the edges of the shutter.

All the photographs were taken on bromo-gelatine dry plates, having the dimension of eight inches by ten. They accordingly covered a region of 12° in declination and 10° in right ascension. On the equator this represents forty minutes of time. Most of the plates were made by Messrs. Allen and Rowell, of Boston, and were of the form known as the "Extra Quick." Cramer's developer was used, containing pyrogallic acid and carbonate of soda.

The photographic work may be divided into three classes. First, the telescope being at rest, photographing the trails of the stars; secondly, with the aid of clockwork, forming charts; and, thirdly, photographing the spectra of the stars. These subjects will be considered in three separate sections.

THEORETICAL CONSIDERATIONS.

The first case to be considered is that of a luminous point at rest. The formation of a chart of the stars when the instrument is perfectly adjusted is an example of this case. Secondly, let the luminous object be a line instead of a point. A moving luminous point, as a star when the telescope is at rest or the adjustment is imperfect, will be considered in this connection. The third case is that of a luminous surface, as a nebula or comet.

To compare the advantages of different forms of instrument, a discussion is given below to show the relation between the dimensions of the lens employed and the light of the faintest star that can be photographed with it.

The following notation will be used: —

$a =$ aperture of lens.
$f =$ focal length of lens.
$t =$ proportion of light transmitted by lens.
$d =$ diameter of the photographic image of the faintest star capable of impressing itself upon the plate.
$m =$ brightness of such a star expressed in stellar magnitudes.
$l =$ ratio of the light emitted by such a star to that of a star of magnitude zero.
$T =$ time of exposure.
$s =$ sensitiveness of plate measured by the amount of light required to produce the faintest perceptible photographic impression.

The value of l will be proportional to d^2 and to s, inversely proportional to a^2 and to t, and may be assumed to be inversely proportional to T. This last assumption is based on experiment, and seems to be justified within wide limits. Then $l = A\frac{d^2 s}{a^2 t T}$, in which A is a constant dependent on the units employed to indicate the magnitudes of the various quantities involved in this equation. Upon Pogson's system of magnitudes, $m = -2.5 \log l$, and hence

$$m = -2.5\,(\log A + 2\log d + \log s - 2\log a - \log t - \log T).$$

The uncertainty in the value of d renders it difficult to compare results in different cases. The principal causes affecting it are, first, variations in the atmospheric refraction. With a given aperture, these variations may be regarded as causing a constant angular deviation of different portions of the beam; d will therefore be proportional to f. It will also increase rapidly if a increases. Secondly, spherical and chromatic aberration of the lens. This will have the same angular value in equally perfect lenses, so that when $\frac{a}{f}$ is constant it will be proportional to f. Its angular value will increase rapidly as a increases. Thirdly, diffraction from the edges of the lens. This error is ordinarily small, and, unlike the other sources of error, increases as the aperture diminishes. Fourthly, a chemical action occurs by which a decomposition of the salts of silver, at the point exposed to the light, extends to the adjacent particles. This effect is very marked in the case of the bright stars, and is of course independent of the dimensions of the lens. The increased size of the images of the bright stars is in part only due to this chemical action. It is also caused by the light diffused by the other sources of error mentioned above, and by the light reflected from the back of the plate. In the faint stars this chemical action is inappreciable, but becomes perceptible when the light is intense. It is therefore very difficult to compare two lenses theoretically, even if we are sure that they differ only in their dimensions. If we assume that d is a constant, so that the fourth of the above causes is the principal one to act, l will depend only on the aperture of the object-glass. Since one magnitude corresponds to a ratio of light of 2.512, an increase of the aperture of 1.585 should permit stars one magnitude fainter to be photographed in the same time. In like manner, increasing the aperture ten times should extend this limit by five magnitudes. In reality this is far from being the case, the actual increase in aperture required being much greater. Again, if the angular diameter of the images is nearly constant, d will be proportional to f, and l will remain the same as long as the angular aperture $\frac{a}{f}$ is constant. On this hypothesis similar lenses, whether large or small, could photograph equally faint stars. The fact lies somewhere between the two, and perhaps it would not be far from the truth to assume that the limiting amount of light was proportional to $\frac{a}{\sqrt{f}}$. When the positions of the stars are to be measured, a large telescope has a very great advantage. The scale is proportional to the focal length, and, since the errors of measurement are nearly constant when expressed linearly, this effect will be inversely as the focal length.

The second case to be considered is that in which the image of the star is slowly traversing the plate. Let v equal the velocity, or distance traversed per second. Then the time of exposure will equal that required by the star to move a distance equal to its diameter, and $T = \frac{d}{v}$. We therefore shall have $l = \frac{A\,d\,s\,v}{a^2\,t}$, and as long as the instrument remains unchanged l is proportional to v. If the telescope is at rest and the motion of the star is due to the rotation of the earth, $v = \frac{2\pi f}{86400}\cos\delta$, and $l = \frac{2\pi f A\,d\,s\cos\delta}{86400\,a^2\,t}$, denoting the declination of the star by δ. When stars of different declinations are photographed with the same instrument, δ is the only variable in the right-hand member of this equation; hence we may write $l = C\cos\delta$, and l is proportional to the cosine of the declination of the star. We then have $m = -2.5\log l = -2.5\log C - 2.5\log\cos\delta$. When we wish to compare the relative brightness of different stars from the intensities of the trails they leave, this correction must first be applied. The trails must first be reduced to a scale of stellar magnitudes, as will be described later (page 211), and then the correction $2.5\log\cos\delta$ added to each. This correction is facilitated by the aid of Table I., which gives for every degree of declination the correction in hundredths of a magnitude.

TABLE I.

δ	Magn	δ	Magn	δ	Magn.	δ	Magn.	δ	Magn.	δ	Magn.	δ	Magn.	δ	Magn	δ	Magn
°		°		°		°		°		°		°		°		°	
0	0.00	10	0.02	20	0.07	30	0.16	40	0.29	50	0.48	60	0.75	70	1.16	80	1.90
1	0.00	11	0.02	21	0.07	31	0.17	41	0.31	51	0.50	61	0.79	71	1.22	81	2.01
2	0.00	12	0.02	22	0.08	32	0.18	42	0.32	52	0.53	62	0.82	72	1.28	82	2.14
3	0.00	13	0.03	23	0.09	33	0.19	43	0.34	53	0.55	63	0.86	73	1.34	83	2.29
4	0.00	14	0.03	24	0.10	34	0.20	44	0.36	54	0.58	64	0.90	74	1.40	84	2.45
5	0.00	15	0.04	25	0.11	35	0.22	45	0.38	55	0.60	65	0.94	75	1.47	85	2.65
6	0.01	16	0.04	26	0.12	36	0.23	46	0.40	56	0.63	66	0.98	76	1.54	86	2.89
7	0.01	17	0.05	27	0.13	37	0.24	47	0.42	57	0.66	67	1.02	77	1.62	87	3.20
8	0.01	18	0.05	28	0.14	38	0.26	48	0.44	58	0.69	68	1.07	78	1.71	88	3.64
9	0.01	19	0.06	29	0.15	39	0.27	49	0.46	59	0.72	69	1.11	79	1.80	89	4.40

It is generally sufficiently precise to carry the computations to tenths of a magnitude. In this case, Table II. is more convenient, especially for polar stars where the correction changes rapidly. The limits of declination within which the corrections of each tenth of a magnitude should be applied are given in this table. The correction for any declination given in the table is found by adding the whole number of magnitudes taken from the top of the column to the tenth of a magnitude at the beginning of the line. The correction for intermediate declinations is the same as that of the next smaller declination given in the table. Thus, the correction will be 0.0 for stars at any declination from 0° 0′ to 17° 15′ inclusive. It will be 1.0 for stars between 65° 22′ and 67° 39′.

TABLE II.

	0		1		2		3		4	
	°	′	°	′	°	′	°	′	°	′
.0	0	0	65	22	80	27	86	13	88	30
.1	17	16	67	40	81	18		33		38
.2	29	26	69	43	82	4		51		45
.3	37	25	71	34		47	87	8		52
.4	43	35	73	15	83	25		23		58
.5	48	39	74	46	84	0		37	89	3
.6	52	57	76	8		32		50		8
.7	56	40	77	22	85	1	88	1		13
.8	59	56	78	30		27		12		17
.9	62	49	79	31		51		21		21

When a star is very near the pole, the cosine of the declination will be proportional to the polar distance p. If this quantity is expressed in minutes of arc, the rate of motion will be proportional to $\frac{p}{3438}$. The correction in magnitudes will then be $2.5 \log .3438 - 2.5 \log p$, or $8.84 - 2.5 \log p$. The correction for the polar distances 1′, 10′, 100′, and 1,000′ will by this formula be 8.84, 6.34, 3.84, and 1.34. A direct computation from $\cos \delta$ gives 8.84, 6.34, 3.84, and 1.36.

Owing to precession, the relative brightness of the trails of the stars will vary from year to year. The effect will of course be very small, except for stars near the pole. As shown above, the correction for declination is $2.5 \log \cos \delta$. The differential coefficient of this expression with respect to δ is $2.5 \times .434 \tan \delta$, or $1.085 \tan \delta$. If the precession in declination for n years is $\frac{20''.45\, n \cos \alpha}{206265''}$, the change in the correction is $.000107\, n \cos \alpha \tan \delta$.

A table of $133.7 \sin \alpha \tan \delta$ is given in Oeltzen (Vol. I. p. xiii) for various values of α and δ. This table may be employed for the present purpose by placing the expression just obtained in the form $.0000008003\, (133.7 \sin \alpha \tan \delta)\, n$, and changing α by 6 hours. The sign is determined by the rule that for stars between 6^h and 18^h of right ascension the correction to the photographic brightness diminishes.

For stars in the immediate vicinity of the pole, when the polar distance expressed in minutes is p, $\tan \delta = \frac{3438}{p}$, and the correction for precession $0.37\, \frac{n \cos \alpha}{p}$.

All of these formulas are of course approximate, and, if used for intervals of time in which the change in right ascension is very great, the neglected terms may have to be considered.

The relative brightness of the trails of the brighter stars, and also of some faint close polars, is given in Table III. The successive columns give the number from the Harvard Photometry, the usual designation of the star, its right ascension and declination for 1885, its brightness to the eye, and the corresponding brightness of the photographic trail. The first eight magnitudes in the last column but one were taken from the Harvard Observatory Annals, XIV. 406. The others are taken from the Proceedings of the American Association, XXXIII. 1, except β *Ursæ Minoris*, which is taken from the Harvard Annals, XIV. 200, and σ *Octantis*, which is taken from the Uranometria Argentina, p. 131.

TABLE III.

H. P.	Desig.	R. A. 1885.	Dec. 1885.	Magn.	Trail.
		m. s.	° ′		
1275	α Canis Majoris	6 40.1	−16 34	−1.4	−1.4
—	α Argus	6 21.4	−52 38	−0.8	−0.3
—	α Centauri . . .	14 31.8	−60 22	−0.1	−0.9
2400	α Bootis	14 10.4	+19 47	0.1	0.0
932	α Aurigæ	5 8.2	+45 53	0.2	−0.3
936	β Orionis	5 9.0	− 8 20	0.2	0.2
3147	α Lyræ	18 33.0	+38 41	0.4	0.0
213	α Ursæ Minoris	1 16.6	+88 42	2.2	−1.9
2500	β Ursæ Minoris	14 51.0	+74 38	2.1	0.6
3077	δ Ursæ Minoris	18 9.0	+86 37	4.3	1.1
1292	51 H. Cephei . .	6 46.7	+87 13	5.3	2.0
3426	λ Ursæ Minoris	19 37.9	+88 58	6.5	2.1
—	DM +89° 3 . .	2 38.8	+89 38	9.2	3.7
—	σ Octantis . . .	18 33.5	−89 16	5.8	1.1
—	DM +89° 37 .	18 24.0	+89 54	10.5	3.6

The conditions needed to photograph a faintly illuminated surface, as a nebula, are quite different. The four sources of error noted on page 187 will here have no effect on the result, except in obscuring details, unless the surface is very small. Using the same notation as before, $l = b\,\frac{f^2}{a^2\,t\,T}$. Accordingly, equally faint surfaces may be photographed by similar lenses, whatever their size, except that a large lens has a slight disadvantage from the greater absorption due to the increased thickness. When, however, detail is to be shown, the advantage of the large scale of the images formed by a lens of long focus at once shows itself. An increase in the angular aperture is, however, a great advantage in photographing a faint surface.

When the different portions of a plate are subjected to a gradually increasing light, up to a certain point no perceptible effect will be produced. The darkening then becomes more and more intense, until a certain maximum effect is produced, and then with a very intense light, like that of the Sun, a reversing action takes place, by which the density becomes less and less. Representing by a curve the relation between the darkening and the total actinic energy received upon any portion of the plate, we find that these curves may differ in three essential particulars. First, the amount of light required to produce the first impression upon the plate. This may be regarded as a measure of the sensitiveness of the plate, or its value for photographing very faint objects. Secondly, one curve may be steeper than another; that is, the increase in darkening may be more marked with one plate than another, with a given increase of light. The greater this increase, the better is the plate adapted to show differences in the light of stars of nearly equal magnitude, or to show details in nebulæ or spectra. On the other hand, the range of such a plate is small, and it will be less adapted for making charts or other pictorial representations. Moderately bright stars will completely decompose the silver particles, and cannot be distinguished from much brighter objects. The brighter portions of a nebula or spectrum will also be burned out, and will fail to show great variations in light as well as plates less sensitive to small changes. Thirdly, the maximum darkness of different plates also varies; but this is a matter of less importance for our present purpose. A fuller consideration of this subject, with measures of the constants of various plates, will be given by Mr. W. H. Pickering in the Proceedings of the American Academy.

In view of the continual improvement in photographic processes, and the increase in sensitiveness that has been attained in the more recent forms of plates, it becomes an interesting question to consider what is likely to limit the results attained. We are already approaching this limit on moonlight nights. The fogging of the plates is so great when the moon is nearly full, that long exposures cannot be used with a telescope of so large an angular aperture as the telescope here employed. A further increase in the sensitiveness of the plates will render it impossible to work to the best advantage in the vicinity of a large city, on account of the illumination of the atmosphere by artificial light. It will then be necessary to take the photographs in more remote regions, or preferably at great elevations, where the reflecting atmosphere is diminished in amount. For these reasons a great increase in the time of exposure, or in the angular aperture of the telescope, is not to be desired. As shown above, with a given linear aperture the light of the sky or other luminous surface will diminish rapidly as the focus is increased. The light of a star will be diminished only so far as the diameter of its image is increased by the increase in focus. A great saving in time and expense might, however, be effected by more sensitive plates, since smaller lenses and shorter exposures could be employed.

In order that the stars shall leave trails, it is not necessary that the telescope shall be at rest. If its motion deviates in any way from that of the star, a trail will evidently be produced having a length proportional to the rate of deviation and to the length of exposure. If the speed of the driving-clock is greater or less than it should be, trails will evidently be formed having a length proportional to the hourly rate of the clock as compared with a sidereal clock, to the time of exposure, and to the cosine of the declination of the star. The light required to produce a trail of given intensity will bear the same relation to that required to produce the same trail when the telescope is at rest, as the hourly rate bears to an hour. Accordingly, if the clock gains or loses one minute an hour, trails will be formed by stars having one sixtieth part of the brightness of those which form similar trails when the telescope is at rest. This corresponds to a difference of about four magnitudes and a half. A rate of a second an hour should give the ratio of one to thirty-six hundred, or nearly nine magnitudes. The limit is soon reached, however, in consequence of the size of the images of the stars, and the impossibility of giving long enough exposures to enable them to traverse distances great enough to form an appreciable trail. The method of electrical control above described enables the rate of the driving-clock to be varied at will. The deviation from this cause can be rendered entirely insensible if desired.

Trails will also be formed if the axis of the instrument is not parallel to that of the earth. If we wish to make the images of the stars perfectly circular, instead of elongated into trails, this is a much more troublesome source of error. The simplest case to be considered is that in which we should give an exposure of twenty-four hours to the region in the vicinity of the north pole. The plate may here be regarded as revolving around a line passing through the optical centre of the object-glass and parallel to the polar axis of the instrument. The intersection of this line with the plate will form a centre around which the plate will appear to revolve. If a photograph should be taken of any fixed point in the sky, it would describe a circle around this point. If a star were situated exactly at the north pole, it would form such a fixed point, and would accordingly describe a circle with a radius equal to the distance between the pole of the earth and that of the instrument. Since the photographic surface sensibly coincides with a sphere whose radius is the focal distance of the lens, the deviation in seconds, s, of the axis may readily be determined from the radius r of this photographic circle. The relation between them will be expressed by the formula $r = \frac{s f}{206265}$, or $s = \frac{206265\, r}{f}$. No star is visible exactly at the pole, nor would it remain there, owing to precession. Adjacent stars will, however, describe nearly the same path, as will be shown below.

Since an exposure of twenty-four hours is impracticable, a portion only of the circle is obtained, the length of which is generally given with sufficient precision by the formula $l = \frac{m\, r}{229}$, in which l is the length of the trail and m the exposure in minutes. Combining this with the previous formula, we deduce $s = \frac{229 \times 206265\, l}{m\, f}$. The curvature of the trail is here neglected, but is readily allowed for if the exposure much exceeds an hour. If the exposure is much less than half an hour, it becomes difficult to detect the curvature, and to know on which side of the trail the centre of the circle lies; in other words, to decide whether the polar axis is too high or too low, to the east or the west. This difficulty may be remedied by stopping the clock and allowing each star to make a second trail for a minute or so by the diurnal motion. When the plate is developed, the trails formed when the clock was on will be parallel and of equal length; the others will be at right angles to a line drawn through the pole, and will have a length proportional to the polar distance. The second trail will also be fainter than the first, if the instrument is nearly in adjustment, except for stars very near the pole. The direction in which the first trail is described may be known from the fact that its following end is always attached to the preceding end of the second trail. Moreover, the direction in the northern hemisphere as seen from the object-glass is always opposite to that of the hands of a watch. Accordingly, if the observer holds the plate so that the first trail is horizontal with the second trail attached to its right-hand end, and the side of the plate to which the film is attached towards him, the centre of the trail will always be above. The simplest rule, however, is to make a second exposure after moving the axis, and to notice the effect on the trail. From this establish an empirical rule, and always hold the plates in the same position. When the trails are very short, it is sometimes better to detach them by covering the plate for a minute or so to prevent their interfering. Care must then be taken in making the exposures that the telescope is not disturbed.

We must next consider the trail described by stars in other portions of the heavens, supposing the only error to be that of the axis of the instrument. If it were possible to photograph a star at the south pole without disturbing the instrument, evidently it would also describe a circle like that described by a star at the north pole, since, if the photographs were taken simultaneously, both stars would always be exactly 180° apart. The path of other stars may be determined by conceiving of two concentric spheres revolving with equal velocity, the outer one around an axis parallel to that of the earth, the inner one parallel to the axis of the instrument. The motion of any point of the outer sphere compared with the inner one will give the required trails. Since the inclination of the axis is assumed to be small, the effect will be the same as if the inner sphere remained at rest and the outer one was moved so that its poles should describe circles around the axis of the inner sphere, but without rotating either sphere. This could be accomplished mechanically by loading the lower half of the inner sphere. If we consider a point upon the equator of the outer sphere, we see that its motion will be exactly north and south, any tendency of the northern pole to move it east or west being always compensated by an equal tendency of the southern pole to move it in the opposite direction. For other declinations, the east and west motion will be reduced by an amount that will always be proportional to the sine of the declination, while the north and south motion will be undiminished, and will always be equal to twice the deviation of the two axes. In the case of stars, it therefore follows that the trails will always be ellipses having their transverse axes north and south. The length of the semi-transverse axis will equal the distance between the pole of the instrument and the north pole, when represented on a sphere having a radius equal to the focal distance. The semi-conjugate axis at the pole will be the same as the semi-transverse axis; it will become zero at the equator, and will vary between these points as the sine of the declination. The trails will therefore vary from circles at the pole to lines running north and south on the equator. If errors are present, due to the rate of the clock as well as to the position of the polar axis, each will produce its effect independently. The form of trail may therefore be constructed geometrically from the principles described above. For testing the instrument, the pole is the best region, since errors in altitude and azimuth in the axis here enter with their full force. At the equator an error in altitude is insensible, as the star is there describing the end of a very elongated ellipse.

To adjust the axis, it may sometimes be found more convenient to replace the sensitive plate by a positive eye-piece with cross-lines. Directing the telescope upon a star near the meridian, if the axis points west of the true pole, the star will appear to be moving to the north, or will move below the horizontal cross-wire. It must then be brought back by one half the amount of the deviation, by moving the axis. The opposite effect will be produced if the axis is directed to the east.

The following discussion of the path described by stars at various declinations, when the axis is not properly adjusted, has been prepared by Professor Searle.

The effects resulting from an imperfect adjustment of the polar axis of any equatorially mounted telescope are partly indicated in treatises upon practical astronomy. Equations relating to the subject here to be considered may be found, for example, in Chauvenet's Spherical and Practical Astronomy, Vol. II., pages 375 and 378; but, for the present purpose, they may be somewhat simplified.

It will be convenient to give the names of instrumental poles and instrumental hour circles to the points of the celestial sphere towards which the ends of the polar axis of the telescope are directed, and the great circles passing through these points. One of the instrumental poles will be situated in the same celestial hemisphere with the star to be photographed. Let γ denote the distance of this pole from the nearer of the two celestial poles, and δ the declination, regarded as positive, of the star. Let p denote the corresponding distance of the star from the instrumental pole, always regarded as positive. Let t denote the angle between the planes of two hour circles, one, which may be called the fixed circle, passing through the instrumental pole, and the other through the star. Let v denote the corresponding angle between the fixed circle and the instrumental hour circle of the star, and consider t and v as equal to 0 when the celestial pole lies between the instrumental pole and the star, so that the star is crossing the fixed circle and $p = \frac{1}{2}\pi - \delta + \gamma$. Suppose t and v, at this time, to be increasing with the diurnal revolution of the star. Then

$$\cos p = \sin \delta \cos \gamma - \cos \delta \sin \gamma \cos t. \qquad (1.)$$

$$\sin v \sin p = \cos \delta \sin t. \qquad (2.)$$

$$\cos v \sin p = \sin \gamma \sin \delta + \cos \gamma \cos \delta \cos t. \qquad (3.)$$

It will be assumed, in order to simplify the inquiry, that the photographic plate is placed so that its plane is perpendicular to that of the fixed circle when $t = 0$. If γ is small, this will be nearly true in practice; in other cases, this will be the most convenient position for the plate if it is to depict the whole of the apparent path of the star with respect to the telescope. The easiest supposition respecting the inclination of the plate to the polar axis of the telescope will be that this inclination is equal to δ; that is, we may assume that the telescope is set to the declination of the star, without regard to error of adjustment. If the clock driving the telescope is correctly regulated, which is here assumed to be the case, the plane of the plate is constantly perpendicular to the plane of an instrumental hour circle, which makes the angle t with the fixed circle. The orthographic projection of this hour circle upon the plate is a straight line, which may be regarded as an axis of abscissas. The intersection of this line with the radius of the sphere perpendicular to it may be assumed as the origin; the point of the sphere to which the radius is directed is at the distance $\frac{1}{2}\pi - \delta$ from the instrumental pole, which will therefore be orthographically projected upon the plate at the distance $\cos\delta$ from the origin. The orthographic projection here employed has the advantage of simplicity; it will not, however, correctly represent the relative dimensions of different parts of the curve described upon the plate by the image of the star, unless γ is very small. But the present inquiry is confined to the general form of the curve, which may be derived as well from the orthographic projection as from one more strictly appropriate to the circumstances of the case. The gnomonic projection would probably best represent the actual curve.

The small circles formed by the intersections of the sphere with planes perpendicular to the axis of the instrument may be called instrumental parallels. Their orthographic projections upon the plate will be elliptical, but the parts of these projections near the origin will in ordinary cases differ little from straight lines. The projection of the instrumental parallel of the star will intersect the axis of abscissas at two points, the distances of which from the origin may be expressed by $\sin(\frac{1}{2}\pi - \delta - p)$ and $\sin(\frac{1}{2}\pi - \delta + p)$. The first of these quantities, which is equal to $\cos(\delta + p)$, will here be employed as one of the data indicating the form of the curve which is described upon the plate by the image of the star. The employment of the second quantity is never necessary, although, when $\frac{1}{2}\pi - \delta < \gamma$, it may sometimes seem more appropriate.

The least distance of the image of the star from the axis of abscissas will be expressed by $\sin(t - v)\sin p$. This will appear upon consideration of the case in which $\delta = 0$, and the inclination of the plate to the axis of the instrument will not affect the length of the projection, provided, as has been supposed, that the plate remains perpendicular to the instrumental hour circle at the angle t from the fixed circle.

The data thus assumed for the position of the image are not the customary rectangular co-ordinates, since the perpendicular denoted by $\sin(t-v)\sin p$ does not intersect the axis of abscissas at the same point with the corresponding projection of the instrumental parallel. Usually, however, these data will differ little from rectangular co-ordinates, and they will serve in all cases to represent the general course of the image of the star upon the photographic plate. The ordinary symbols for rectangular co-ordinates will therefore be adopted, so that $x = \cos(\delta + p)$, and $y = \sin(t - v)\sin p$.

From (1), $\cos p = \sin(\delta - \gamma) + \cos\delta\sin\gamma(1 - \cos t)$; this quantity progressively increases from $\sin(\delta - \gamma)$ when $t = 0$ to $\sin(\delta + \gamma)$ when $t = \pi$. The value of x must increase and diminish with that of $\cos p$, unless $\delta + p$ is negative or greater than π. But δ and p are always positive by supposition, and the greatest value of p is $\frac{1}{2}\pi - \delta + \gamma$, which can never exceed $\pi - \delta$; x therefore increases while t increases from 0 to π, returning through the same series of values as t increases from π to 2π, so that the value of x is the same for any two values of t equidistant from 0 or from π, no other value of x being identical with this.

By definition,

$$y = \sin(t - v)\sin p = \sin t\cos v\sin p - \cos t\sin v\sin p.$$

Hence, from (2) and (3),

$$y = \sin t\sin\gamma\sin\delta + \sin t\cos t\cos\gamma\cos\delta - \sin t\cos t\cos\delta;$$

and after reduction

$$y = \sin\gamma\sin\delta\sin t - \sin^2\tfrac{1}{2}\gamma\cos\delta\sin 2t. \qquad (4.)$$

Differentiating this equation with respect to t, we have

$$\frac{dy}{dt} = \sin\gamma\sin\delta\cos t - 2\sin^2\tfrac{1}{2}\gamma\cos\delta\cos 2t.$$

From (1),

$$\frac{d\cos p}{dt} = \sin\gamma\cos\delta\sin t;$$

we have also

$$\frac{dx}{d\cos p} = \frac{\sin(\delta + p)}{\sin p} = \frac{\sin(\delta + p)}{\sin(\delta + p - \delta)} = \frac{1}{\cos\delta - \sin\delta\cot(\delta + p)}.$$

Accordingly,

$$\frac{dx}{dt} = \frac{\sin\gamma\cos\delta\sin t}{\cos\delta - \sin\delta\cot(\delta + p)},$$

and

$$\frac{dy}{dx} = \frac{[\cos\delta - \sin\delta\cot(\delta + p)]\,[\sin\gamma\sin\delta\cos t - 2\sin^2\tfrac{1}{2}\gamma\cos\delta\cos 2t]}{\sin\gamma\cos\delta\sin t};$$

this may be reduced to the form

$$\frac{dy}{dx} = \sin\delta\,[1 - \tan\delta\cot(\delta + p)]\,[(1 - \tan\tfrac{1}{2}\gamma\cot\delta\cos t)\cot t + \tan\tfrac{1}{2}\gamma\cot\delta\sin t].$$

In this expression $\sin\delta\,[1 - \tan\delta\cot(\delta + p)]$ cannot become negative, since δ and p are positive, while δ does not exceed $\frac{1}{2}\pi$, and when $\cot(\delta + p)$ is positive, $\tan\delta\cot(\delta + p)$ is a proper fraction. It reaches the value 1 only in the case of the passage of the star through the instrumental pole.

Equation (4) shows that y reaches the value 0 when

$$\sin\tfrac{1}{2}\gamma\sin t\,(\sin\delta\cos\tfrac{1}{2}\gamma - \cos\delta\sin\tfrac{1}{2}\gamma\cos t) = 0;$$

that is, when $t = 0$, when $t = \pi$, and when $\cos t = \tan\delta\cot\frac{1}{2}\gamma$; the last condition requires that δ shall not exceed $\frac{1}{2}\gamma$, and in that case will occur at some value of t from 0 to $\frac{1}{2}\pi$, and at the corresponding value between $\frac{3}{2}\pi$ and 2π. The points of the curve where these values occur are accordingly situated upon the axis, and the general statement of the variations of x, already given, shows that x has the same value at each point. Hence the two points are identical. It has been shown that, in the expression for $\frac{dy}{dx}$, $\sin\delta\,[1 - \tan\delta\cot(\delta + p)]$ is positive. The remaining factor, since $\tan\delta\cot\frac{1}{2}\gamma = \cos t$, is reduced to $2\sin t\cos t$, which is positive for the smaller, and negative for the larger value of t. As dx is also positive for the smaller, and negative for the larger value, dy is positive in both cases. When $t = 0$, and $\delta < \frac{1}{2}\gamma$, $\frac{dy}{dx} = -\infty$; so also when $t = \pi$, $\frac{dy}{dx} = -\infty$.

Hence, when $\delta < \frac{1}{2}\gamma$, the curve consists of two closed branches with a common point, resembling a lemniscata; it will be shown below that, when $\delta = 0$, the equation of the curve represents a species of lemniscata.

When $\delta = \frac{1}{2}\gamma$, $\cos t = \tan\delta\cot\frac{1}{2}\gamma$ only when $t = 0$; the lower branch of the curve, accordingly, disappears. The term $(1 - \tan\frac{1}{2}\gamma\cot\delta\cos t)\cot t$ becomes $2\sin^2\frac{1}{2}t\cot t$, which may be written in the form $\sin\frac{1}{2}t\,(\cos\frac{1}{2}t - \sin\frac{1}{2}t\tan\frac{1}{2}t)$; when $t = 0$, this vanishes, and also the term $\tan\frac{1}{2}\gamma\cot\delta\sin t$; hence $\frac{dy}{dx} = 0$. As this value occurs at the minimum of x, the lower branch of the curve vanishes in a cusp. The value of p in this case is $\frac{1}{2}\pi + \frac{1}{2}\gamma$.

When $\delta > \frac{1}{2}\gamma$, $y = 0$ only when $t = 0$ or when $t = \pi$. When $t = 0$, $\frac{dy}{dx} = \infty$; when $t = \pi$, $\frac{dy}{dx} = -\infty$, as before. For values of t near 0, $\frac{dy}{dx}$ is relatively small as compared with the corresponding values when t is near π. The curve is therefore ovoid.

When $\delta = \frac{1}{2}\pi$, $\frac{dx}{dt} = 0$, and $\frac{dy}{dt} = \sin\gamma \cos t$; in this case $p = \gamma$, $x = -\sin\gamma$, and $y = \sin\gamma \sin t$. With the system of co-ordinates which has been employed, this represents the circle in which the celestial pole appears to move round the instrumental pole.

When $\delta < \frac{1}{2}\gamma$, an extreme value of y will occur for some value of t between 0 and $\frac{1}{2}\pi$. This is apparent from the values already found for which $y = 0$. The extreme values of this branch of the curve will be numerically greatest when $\delta = 0$, as is shown by (4), where the two terms of the value of y have contrary signs for values of t between 0 and $\frac{1}{2}\pi$. Their difference, accordingly, will be largest when the first term has its least and the second its greatest numerical value. This occurs when $\delta = 0$, and the value of y is then $-\sin^2\frac{1}{2}\gamma \sin 2t$; at its extreme values, when $t = \frac{3}{4}\pi$ or $t = \frac{1}{4}\pi$, $y = \pm \sin^2\frac{1}{2}\gamma$. The corresponding maximum and minimum in the other branch of the curve have in this instance the same value. The general condition for a maximum or minimum of y appears from the value of $\frac{dy}{dt}$ to be $\cos t\,(\cos t - \frac{1}{2}\cot\frac{1}{2}\gamma \tan\delta) = \frac{1}{2}$. This is satisfied by $t = \pm \frac{1}{4}\pi$, if $\delta = 0$, as has just been shown; also by $\cos t = 1$, if $\delta = \frac{1}{2}\gamma$; this result, also, has been considered above. In other cases, the values of $\cos t$ required for the maximum and minimum of y are found, by the solution of the quadratic equation just given, to be

$$\tfrac{1}{4}\left(\cot\tfrac{1}{2}\gamma \tan\delta \pm \sqrt{8 + \cot^2\tfrac{1}{2}\gamma \tan^2\delta}\right).$$

To find the greatest and least possible values of y, we have also, from (4),

$$\frac{dy}{d\delta} = \sin\gamma \cos\delta \sin t + 2\sin^2\tfrac{1}{2}\gamma \sin\delta \sin t \cos t,$$

which must vanish for the extreme values required, so that $\cos t = -\cot\frac{1}{2}\gamma \cot\delta$. Equating the two expressions thus found for $\cos t$, we have

$$\cot\tfrac{1}{2}\gamma \cot\delta = -\tfrac{1}{4}\left(\cot\tfrac{1}{2}\gamma \tan\delta \pm \sqrt{8 + \cot^2\tfrac{1}{2}\gamma \tan^2\delta}\right),$$

and, after reduction, $\tan^2\delta = \frac{2}{\tan^2\frac{1}{2}\gamma - 1}$. By supposition, γ is positive, and cannot exceed $\frac{1}{2}\pi$; hence $\tan^2\frac{1}{2}\gamma$ never exceeds 1, and no extreme value of y can occur unless $\gamma = \delta = \frac{1}{2}\pi$. Accordingly, the numerical value of the maximum and minimum of y for a given value of δ increases from $\sin^2\frac{1}{2}\gamma$ when $\delta = \frac{1}{2}\gamma$ to $\sin\gamma$ when $\delta = \frac{1}{2}\pi$, without reaching an algebraic maximum unless $\gamma = \frac{1}{2}\pi$, when $\sin\gamma$ denotes an extreme, as well as a final value.

No material modifications of the expressions already given are apparently required when the star passes between the instrumental and celestial poles. The equation of the curve in two special cases is given below.

When $\delta = 0$, the co-ordinates are rectangular;

$$x = \cos p = - \sin \gamma \cos t, \qquad \text{and} \qquad y = - \sin^2 \tfrac{1}{2} \gamma \sin 2\ t.$$

Hence

$$\cos^2 t = \frac{x^2}{\sin^2 \gamma}; \quad \sin^2 t = \frac{\sin^2 \gamma - x^2}{\sin^2 \gamma}; \quad \sin^2 2\,t = \frac{4\,x^2\,(\sin^2 \gamma - x^2)}{\sin^4 \gamma};$$

and

$$y^2 = \frac{4 \sin^4 \frac{1}{2} \gamma}{\sin^4 \gamma}\, x^2\,(\sin^2 \gamma - x^2) = 2 \sec^4 \tfrac{1}{2} \gamma\, x^2\,(\sin^2 \gamma - x^2).$$

This is the equation of a curve in the general form of a lemniscata. If γ is sufficiently small, it may be reduced to $y^2 = 2\,x^2\,(\gamma^2 - x^2)$, whence $x^4 - \gamma^2 x^2 = - \frac{1}{2} y^2$, and $x^2 = \frac{1}{2}(\gamma^2 \pm \sqrt{\gamma^4 - 2\,y^2})$. Accordingly, for any real value of x, y cannot exceed $\frac{1}{\sqrt{2}} \gamma^2$, and x cannot exceed γ; if γ is infinitesimal, y must be infinitesimal with respect to x, so that the lemniscata becomes a straight line.

In all cases, when γ is so small that we may substitute γ for $\sin \gamma$ and 1 for $\cos \gamma$, the difference between $\frac{1}{2} \pi$ and $\delta + p$, which never numerically exceeds γ, is a quantity of the same order; so also, accordingly, is x. Let $c = \frac{1}{2} \pi - \delta$;

$$\sin (c - p) = \cos \delta \cos p - \sin \delta \sin p = \cos (\delta + p) = x.$$

As x is small, we may also write $x = c - p$, $p = c - x$, and $\cos (c - p) = \cos x = 1$ Since

$$\cos p - \cos c = 2 \sin \tfrac{1}{2} (c - p) \sin \tfrac{1}{2} (c + p),$$

$$\cos p - \cos c = 2 \sin \tfrac{1}{2} x \sin (c - \tfrac{1}{2} x) = x\,(\sin c - \tfrac{1}{2} x \cos \mathrm{c}).$$

Also, from (1), $\cos p - \cos c = \cos p - \sin \delta = - \gamma \cos \delta \cos t$; hence $x = - \frac{\gamma \sin c \cos t}{\sin c - \frac{1}{2} x \cos c}$, where the term of the denominator containing x may be omitted, so that $x = - \gamma \cos t$. From (4), $y = \gamma \sin \delta \sin t$. Hence $\cos^2 t = \frac{x^2}{\gamma^2}$, $\sin^2 t = \frac{y^2}{\gamma^2 \sin^2 \delta}$, and $\frac{x^2}{\gamma^2} + \frac{y^2}{\gamma^2 \sin^2 \delta} = 1$. The curve is therefore an ellipse, becoming a circle of the radius γ when $\delta = \frac{1}{2} \pi$, and a straight line, as already shown, when $\delta = 0$, since in that case $y = 0$.

The general results of the inquiry, accordingly, are that, without restriction as to the amount of the error of adjustment, the curve described by the image of a star situated on the equator is a species of lemniscata; with an increase in the declination of the star, the lower branch of the curve becomes smaller and narrower, and disappears in a cusp when the declination is equal to half the error of adjustment. For greater declinations, the curve is ovoid, and at the pole it is circular. If the error of adjustment is sufficiently small, the curve is a circle at the pole, a straight line at the equator, and an ellipse in intermediate declinations, as has been stated on page 195.

TRAILS.

Various advantages accrue to the method of photographing the stars without moving the telescope. Each star as it passes through the field leaves a trail which appears on the plate as a fine line, forming part of a circle having the pole as a centre. The first advantage of such a line is, that it is distinguished with certainty from a defect in the plate. When the photograph is to be used as a measure of stellar magnitude, the trail shows that the plate has the same sensitiveness throughout. In ordinary plates this condition appears to be perfectly fulfilled. The trails appear as lines whose intensity is perfectly uniform within the limits of accuracy of which the comparison is capable. Small differences in light are much more perceptible in the trails than in the circular images formed when the telescope is driven by clockwork. The principal objections to photography as a means of determining the brightness of the stars are, first, that for slight differences in brightness the photographic images differ less than the real images. This objection is, however, counterbalanced by the possibility of repeating indefinitely doubtful measures, and of comparing a large number of similar trails under nearly the same conditions. Secondly, a variation in focus in different portions of the plate may affect the measures. A star out of focus may leave a broad trail and appear brighter than another which gives a narrow trail in consequence of its being more nearly in focus. The fact that the photographic intensity will vary greatly with the color can scarcely be called an objection. We wish to know the true relative intensities of the light of the stars, and not merely their relative brightness as judged by the eye. As long as the spectra of the objects compared are the same, that is, as long as the light of any given wave-length emitted by each bears the same proportion to the whole, all methods of measurement will give the same result. In other words, the relative intensity will appear to be the same, whether it is measured by the eye or by the sensitive plate. This is the more precise statement of the case which is commonly expressed by saying that the color is the same. When the spectra differ, and the colors are unlike, no single number will properly express the ratio of the two lights. The only true comparison is by a series of numbers which express the ratio of the light for each different wave-length. When, therefore, we say that a red and a blue star appear equally bright, we merely indicate that the entire radiation affects the eye equally. The visual result will not in general differ much from what would be attained if all the light had a wave-length .00006 cm., or 6000 ten-millionths of a millimetre. The photographic plate gives a more precise summing up of all the radiations, since no difference of color appears in the final picture, but the mean wave-length is not far from 4000 ten-millionths of a millimetre. Accordingly, blue stars will appear comparatively much brighter in the photograph, and red stars brighter to the eye. Their relative light can be fully determined only by the comparison of the spectra, which will be considered later. Meanwhile the photograph furnishes an excellent test of the color of a star, since on comparison with the visual brightness the stars which are faint photographically may be assumed to be red, and the bright ones blue. As the difference amounts to several magnitudes, it furnishes a test much more sensitive than that of the eye. Again, this method is applicable to the faintest stars visible, when the difference in color is quite imperceptible by any other means.

The first tests that were made of the photographic lens, and before it was mounted equatorially, consisted in directing it to the pole, and photographing the trails of the polar stars. This is probably the best method of testing the quickness of any given form of lens, plate, or developer. It may be employed by any photographer, as it is only necessary to turn the camera to the Pole-star and leave it exposed for any convenient time, as half an hour. On developing the plate, the faintest stars shown measure the sensitiveness. Varying either the lens, plate, or developer gives us a means of studying the quality of each.

An excellent means of securing an automatic record of the cloudiness during the night consists in exposing a plate in this way. A long focus lens should be used, but it need not be carefully constructed. The slide should be opened in the evening as soon as it is dark, and it must be closed before the morning twilight. This may be done automatically by an alarm-clock. On developing the plate, the Pole-star will describe a circular arc having a length of 15° for each hour of exposure. The time of passage of any clouds will be marked by interruptions of greater or less length. Such an instrument also forms a photographic watch-clock. The watchman must cover the lens at intervals for a minute or so, each of which will be indicated upon the plate when it is developed.

When the positions of the stars are to be determined photographically, the trails possess some especial advantages. The edges are well defined, and the errors introduced by the irregularities of the clockwork and the shaking of the telescope when in motion are avoided. The declinations can be measured with greater accuracy than the right ascensions. For the latter it is best to make a number of breaks at specified times, thus breaking up the lines into a number of dots whose centres can be determined with accuracy. Much care is necessary to avoid touching the telescope when covering or uncovering it, as the slightest flexure is sufficient to distort the ends of the trails. The measures are necessarily relative except in the case of polar stars, whose absolute declinations may be determined if the centre of the circles constituting the trails can be fixed with sufficient precision.

Unfortunately, the method of trails is not applicable to very faint stars unless they are near the pole. A close polar star no brighter than the fourteenth magnitude gives a satisfactory trail, but equatorial stars fainter than the eighth magnitude have not as yet been photographed in this way, on account of their rapid motion.

As stated above, short trails are produced whenever the telescope is not perfectly adjusted. This is an objection to the appearance of the images upon a chart, and prevents the faintest stars from forming images. On the other hand, the advantages of distinguishing the images from defects in the plate, and the greater accuracy with which the brightness can be measured, may render it advisable to employ this method.

A wide field of work appears open in the application of photography to meridian instruments, or to the almucantar. The sensitive plate should be substituted for the reticule, and the position marked by a graver attached to the tail-piece of the telescope. The times may be indicated by covering and uncovering the object-glass automatically by the sidereal clock. The intervals should be determined by trial, so as to give a series of nearly circular dots separated by as short intervals as possible. Another method is to attach the plate to the armature of an electro-magnet, the current being made and broken at regular intervals. Two series of alternate lines of dots are thus formed. A large number of stars may be recorded on a single plate. The principal advantage of this method would be its freedom from personal equation. It is therefore especially adapted to longitude campaigns. Moreover, a high degree of skill is not required by the observer. It would not be necessary to employ a large telescope in this work. A 3-inch object-glass with a focal length of 44 inches would give a sixth-magnitude star as well as an eighth-magnitude star is shown in the Bache telescope.

A large number of photographs have been taken of the immediate vicinity of the pole, both with and without clockwork. A special section of this memoir is devoted to the discussion of a portion of them. (See page 218.)

The second research to be described is undertaken to determine the light of all of the brighter stars. In order to include all portions of the sky, several exposures are made on each plate. The region to which each star belongs is indicated by varying the time of exposure. Since the length of the trail is proportional to this time, by giving two or more exposures to each region each star may be made to indicate the region in which it is situated by a series of characters like those of the Morse telegraphic alphabet. Each plate covers a region 10° square, and therefore extends over 40 minutes on the equator, and more in other declinations. Eight regions are taken on each plate in the first series. The settings are made at —20°, —10°, 0°, +10°, +20°, +30°, +40°, and +50°. The region covered therefore extends from —25° to +55°. One minute is devoted to each region. The first exposure lasts as many seconds as there are degrees of declination in the southern edge of the region. A break then occurs for ten seconds, and for the last five regions, that is, for those north of the equator, the second exposure lasts during the remainder of the minute. For the first three regions, a second break of ten seconds is made, extending from the fortieth to the fiftieth second. The regions covered in each case, the length of the exposures, and the appearance of the trails, are as follows: —

−25° to −15°	25 seconds,	5 seconds,	10 seconds,	—— - –
−15° “ − 5°	15 “	15 “	10 “	– — –
− 5° “ + 5°	5 “	25 “	10 “	- —— –
+ 5° “ +15°	5 “	45 “	. . .	- ————
+15° “ +25°	15 “	35 “	. . .	— ———
+25° “ +35°	25 “	25 “	. . .	—— ——
+35° “ +45°	35 “	15 “	. . .	——— —
+45° “ +55°	45 “	5 “	. . .	———— -

These plates are to be taken for every 40 minutes throughout the entire twenty-four hours of right ascension. Another series is taken for every alternate twenty minutes, and, to make these overlap still better, the declination is diminished for each of them by 5°. Accordingly, the centres of the regions in the second series coincide with the corners of the regions of the first series. Every star will therefore appear on at least two regions, and if near the corner of one, it will be near the centre of the other. Owing to the convergence of the meridians, some stars will appear on more than two plates. The total area to be covered is about 25,000 square degrees, and each plate will cover 800 degrees. As the series will contain 72 plates, the whole space will be covered on the average about two and a quarter times. As we go north, the lines become shorter, and therefore fainter stars will leave trails. At the northern limit the lines will have but little over one half their length on the equator, and stars half a magnitude fainter will appear. The most northern region will have one exposure of 45 seconds, which even at that declination will give a line long enough to be readily compared with the others.

Another series of photographs is made of the polar regions. These are taken at intervals of one hour in right ascension. Three regions are photographed on each plate. The first extends from +65° to +75°, and has an exposure of 30^s, an interval of 30^s, and an exposure of 120^s. The second extends from +75° to +85°, and has an exposure of 30^s, an interval of 30^s, and an exposure of 240^s. The third region extends from +75° to +85°, and is below the pole. The exposures are the same as in the first region, but as the stars are moving in the opposite direction, the short line now comes on the opposite side of the long one. The regions observed at lower culmination serve to correct the scale for portions of the sky differing by twelve hours in right ascension. They also serve to determine the law regulating the atmospheric absorption. This is, however, much better determined by the next series of photographs. Three regions are photographed on each plate, all extending from +55° to +65°. The first is on the meridian above the pole, and is made by an exposure of 10^s, an interval of 10^s, and an exposure of 40^s. The second region has the same exposure, but is taken below the pole and at an hour angle of thirty minutes west, that is, it contains stars that have not yet culminated. The third region is also below the pole thirty minutes east. Two equal exposures of 30^s each are given, separated by an interval of 10^s. These plates are taken at intervals of twenty minutes in right ascension, and in general one is exposed each night. Two regions are photographed at lower culmination for one at upper culmination, because the stars form so much fainter images when low that comparatively few are obtained at each exposure.

The number of stars shown in these plates, especially in those relating to the polar regions, is very large. Even if it should prove impracticable to identify and measure them all, they will have a value as a permanent record of the condition of the sky at the present time. An illustration of this occurred in Plate 117, which was taken on November 9, 1885. It included the region in which the new star in Orion was discovered on December 13. No evidence of the new star is visible, although the adjacent stars DM. +19° 1106 and DM. +20° 1156 are so well shown as to be easily seen in a paper positive. The magnitudes of these stars in the Durchmusterung are 6.8 and 7.2 respectively. After allowing for the difference in color between these stars and the new star, it is evident that the latter must have been much fainter on November 9 than at the date of discovery. It is believed that no other positive evidence of this fact has been shown to exist.

CHARTS.

In the formation of charts of the stars by photography, we have a definite model to copy. It is not likely that any one will attempt to construct by eye observations charts of any considerable portion of the sky which will be more complete than those of Peters and Chacornac. If then charts equal to these can be obtained by photography, it may be regarded as an entirely satisfactory solution of the question. The area of these charts is 5° square, and their scale is 6 cm. to 1°, or three times the scale of the Durchmusterung. This scale corresponds to a focal length of 343.7 cm. or 135.3 inches. But it is impossible, without enlargement, to print the finest details visible on a good photograph, and, if printed, they could not be seen without a magnifying glass. The necessity of such a glass would greatly interfere with the general utility of star charts, especially when they are to be compared with the stars at night. Accordingly, the plan of enlarging the photographs does not seem objectionable, although some of the finer detail is lost. The scale of the photographs taken with the telescope described on page 184 is 2 cm. to 1°. If then they are enlarged three times, their scale will be the same as that of the charts named above. Lenses are made for ordinary photographic purposes which will include a field of view of 60°, or even 90°, without serious distortion. A photograph of the stars is, however, a far severer test. The distortion becomes perceptible even at a few degrees from the centre. With a single achromatic lens, the distortion is perceptible within a single degree; but with the compound achromatic, such as that of the telescope just mentioned, a much larger angle may be covered satisfactorily. The distortion at the sides of the plates, 5° from the centre, is not very large; at the corners of a plate 5° square, about 3°.5 from the centre, the errors are so small that they will not seriously affect the value of a map.

The advantages of this plan for constructing star charts are its economy and the rapidity with which the work can be performed. When several exposures are made on each plate, an error in one will ruin the whole. A single exposure of one hour is here proposed, which also diminishes the danger of interruption by clouds. The apparatus works automatically, and an observer is not needed who shall continually correct the motion of the clockwork by watching a star through an attached telescope. A great saving in fatigue is thus effected, and skilled labor is not required, since the work may easily be reduced to a routine.

The cost of continuing the work throughout the entire night would be small, since it would only be necessary for the observer to change the plate and readjust the instrument once an hour. If desired, the intervening time could be employed in other observations. The average length of a night, after allowing for twilight, is about ten hours. It would not be difficult to find a location where four nights in every week would be clear. This would give for the maximum capacity of a single photographic telescope nearly two thousand plates annually. The area covered by each plate is twenty-five degrees square. The total area of the sky is about forty thousand degrees square. Sixteen hundred plates would therefore be required to map the entire sky. Two stations must be employed to reach both northern and southern stars, and it therefore follows that it would be possible to prepare in this way a map of the whole sky in a single year. The final charts would not show the faintest stars that could be obtained by photography with larger instruments, but would give about as many stars in a given area as are contained in the charts of Peters and Chacornac. The charts should be carefully compared with the original negatives, to remove defects which might be mistaken for stars. To avoid the need of this comparison, the polar axis of the instrument may be moved slightly in azimuth. As shown on page 195, each star will then leave a short vertical trail. These can be distinguished with certainty from defects in the plate, and will give a more accurate indication of the brightness of the stars than can be derived from circular images.

Stellar Spectra.

An investigation of the photographic spectra of the stars was conducted on an entirely different method from that employed by previous investigators, which has been described on page 182. A large prism was constructed, and placed in front of the object-glass, as was first suggested and tried by Father Secchi in his eye observations of stellar spectra.

The great advantages of this method are, first, that the loss of light is extremely small, and, secondly, that the stars over the entire field of the instrument will impress their spectra upon the plate. As a result, while previous observers have succeeded in photographing the spectrum of but one star at a time, and have not obtained satisfactory results from stars fainter than the second or third magnitude, we have often obtained more than a hundred spectra on a single plate, many of them relating to stars no brighter than the seventh or eighth magnitude.

The first experiments were made in May, 1885, placing a 30° prism in front of the object-glass of the lens described on page 182. No clockwork was used, the spectra being formed of the trails of the stars. In the spectrum of the Pole-star over a dozen lines could be counted. In the spectrum of α *Lyræ* the characteristic lines were shown very clearly. Exposures of two or three minutes were usually employed, although one minute gave an abundant width. In the spectrum of α *Aquilæ*, besides the lines seen in α *Lyræ*, some of the additional faint lines noticed by Dr. Draper were certainly seen.

In the autumn of 1885, two prisms were constructed, having clear apertures of 20 cm. and angles of about 5° and 15°. They could be placed over the object-glass of the photographic telescope without reducing the aperture. The second of these prisms was that actually employed in the experiments described below.

The prism was always placed with its edges horizontal when the telescope was in the meridian. The spectrum then extended north and south. If clockwork was attached, a line of light would be formed too narrow to show the lines of the spectrum satisfactorily. The usual method of removing this difficulty is the employment of a cylindrical lens to widen the spectrum; but if the clockwork is disconnected, the motion of the star will produce the same effect. Unless the star is very bright, the motion will, however, be so great that the spectrum will be too faint. It is only necessary to vary the rate of the clock in order to give any desired width to the spectrum. A width of about one millimetre is needed to show the fainter lines. This distance would be traversed by an equatorial star in about twelve seconds. The longest time that it is ordinarily convenient to expose a plate is about an hour. If then the clock is made to gain or lose twelve seconds an hour, it will have the rate best suited for the spectra of the faintest stars. A mean-time clock loses about ten seconds an hour. It is only necessary to substitute a mean-time clock for the sidereal clock to produce the required rate. It was found more convenient, however, to have an auxiliary clock whose rate could be altered at will by inserting stops of various lengths under the bob of the pendulum. One of these made it gain twelve seconds in about five minutes, the other produced the same gain in an hour. The velocity of the image upon the plate when the clock is detached could thus be reduced thirty or three hundred and sixty times. This corresponds to a difference of 3.7 and 6.1 magnitudes respectively. Since the spectrum of a star of the second magnitude could be taken without clockwork, stars of the sixth and eighth magnitudes respectively could be photographed equally well with the arrangement described above.

A number of photographs were taken of various portions of the sky, and to secure images of all the brighter stars the following system was also adopted.

Four exposures of five minutes each were made, setting the telescope at —10°, 0°, +10°, and +20°. The first of the two stops was used in each case, so that each spectrum had a width of about a millimetre. As the deviation of the prism is about 9°, the centre of the region photographed at the first exposure had a declination of —19°, and extended from —24° to —14°. The four exposures covered a region forty minutes of time in width, and extending from —24° to +16°. Thirty-six plates are required to complete this series, taken at intervals of forty minutes sidereal time, and beginning at $0^h\ 20^m$. Thirty-six more plates are taken at intervals of forty minutes, beginning at $0^h\ 0^m$, the declinations being diminished by five degrees. They cover the region from —29° to +11°, and stars near the corners of the plates in the first series are near the centres of the second series of plates. The region from +11° to +56° is similarly covered by seventy-two plates, arranged as before, in two series. The settings in declination for the first of these are 30°, 40°, 50°, and 60°, and of the second series 25°, 35°, 45°, and 55°. The length of each exposure is five minutes. Finally, the northern stars are included in thirty-six plates arranged in two series. The first of these contain three exposures, setting at declinations of 70°, 80°, and 90°, and at intervals in right ascension of one hour and twenty minutes. The right ascension of the centre of the first plate of this series is $0^h\ 40^m$. For the second series of eighteen plates, the declinations are diminished by 5°. In right ascension, they lie midway between those of the other series, the first being at $0^h\ 0^m$.

Photographs were also taken of the spectra of the fainter stars in certain regions. The auxiliary clock was set so that it should gain about ten seconds in an hour, and a single exposure of about an hour was made upon each plate. The work of photographing the entire sky by this process proved to be too large to be undertaken by the aid of the Bache Fund. Fortunately, Mrs. Henry Draper, as a memorial to her husband, has made provision for continuing this investigation at the Observatory of Harvard College. The results will therefore be described more fully elsewhere.

BRIGHT STARS IN THE PLEIADES.

As an example of some of the results to be derived from stellar photographs such as have been described above, the following examination has been made of several photographs of the Pleiades. The relative brightness of the principal components of this group has been determined from four photographs, Nos. 209, 248, 327, and 361. The first of these plates was taken on December 15, 1885. It was exposed for 5 minutes with the clock on, then the telescope was moved 1° in declination, and exposed for 1 minute with the clock on again. The clock was then stopped, and after an interval of 30 seconds a trail was formed for 30 seconds. Plate 248 was taken on January 6, 1886. An exposure of 10 minutes was given with the clock on, and this was followed by a trail of 1 minute. Plate 327 was taken on January 23, 1886, without clockwork. Eight exposures were given, having the lengths 10^s, 5^s, 2^s, 1^s, 1^s, 1^s, $0^s.5$, $0^s.5$, $0^s.5$, and 40^s respectively. The objective was covered for a few seconds between each exposure. Unfortunately, in putting on the cap, a slight pressure on the telescope brought the images slightly out of line. Plate 361 was taken in a similar manner on February 9, 1886, but a much greater number of exposures of various lengths were made. From Plate 327, it appeared that some stars, the trails of which were visible when the exposure was sufficiently long, produced no effect with an exposure of a single second. The experiment was therefore tried with Plate 361, during a portion of the time, of making short breaks between exposures, lasting for several seconds. Measures could thus be made of the positions of much fainter stars.

A scale for measuring the relative intensities of these trails was constructed from No. 15. This photograph was taken, August 15, 1885, by pointing the telescope to the north pole, and giving a series of exposures of ten minutes each with different apertures. The clockwork was detached, so that the telescope was at rest, and the aperture was varied by inserting a series of circular diaphragms, having diameters of 2.07, 3.12, 4.92, 7.77, 12.33, and 19.55 cm. The last gave nearly the full aperture of the telescope, the others reduced it by quantities which respectively correspond to 4.86, 3.99, 3.00, 2.01, and 1.00 magnitudes. Each star accordingly left a trail consisting of six short lines connected together at the ends, and each representing a difference in light from that next it of one magnitude. The smallest aperture was however too large by about 0.1 cm., so that the interval between it and the preceding, expressed in magnitude, was only 0.87. The portion of the plate containing the trails of δ *Ursæ Minoris* and 24 *Ursæ Minoris* was cut out and attached to a piece of cardboard, so that it could be laid upon the image of the star to be measured. The brightest portion of the trail of δ *Ursæ Minoris* was assumed to represent the magnitude 4, and the faintest portion the magnitude 9. All of these results have been diminished by one magnitude to make the scale agree more nearly with that in common use. Each trail to be measured was compared directly with this scale, the fraction of a magnitude being estimated to tenths. After measuring in this way all the trails visible on each of the plates, the results were brought together, and every star found on either of the plates was looked for on all the others. Residuals were next taken from the mean of the measures, and exceeded three tenths of a magnitude in six cases only. One of these equalled five tenths, the others four tenths of a magnitude. Another estimate was made in each of these cases, with results which are given in the remarks following Table IV. The mean of this estimate and that originally made has been employed in the table. All of the measurements were made by Miss N. A. Farrar, and were entirely independent, even in the case of the repeated stars.

To determine the character of the spectra of the stars in the Pleiades, Plate 337 was taken on January 26, 1886. The exposure was 34 minutes, and the width of the spectra was about 0.06 cm. The spectra of nearly forty stars of this group are shown upon this plate, besides a large number of adjacent stars, since the region covered is ten degrees square. Nearly all the brighter stars in the Pleiades have a spectrum of the first type, in which the spectrum is covered by a series of well-marked lines at regular intervals, including the lines C, F, G, *h*, and H of the solar spectrum. The line K is wanting, or at least is too faint to be visible.

The results are given in Table IV., in which the stars are arranged in the order of their photographic brightness. Stars leaving trails on all four plates are given first, followed by those contained on three plates, two plates, and one plate, respectively. The first column gives the number of the star in the Catalogue of Wolf published in the Annales de l'Observatoire de Paris, Mémoires, Tom. XIV., Deuxième Partie. This is followed by the designation employed by Bessel for the star, the Durchmusterung number, the right ascension and declination for 1885, and the mean photographic magnitude. No correction is applied for the error in the diameter of the smallest diaphragm. The effect of diffraction would be to compensate for this error. The uncertainty in this quantity, and also in the limiting magnitude photographed, renders the magnitudes of the fainter stars somewhat doubtful. The next column gives the residuals in tenths of a magnitude, found by subtracting from the observed magnitudes on Plates 209, 248, 327, and 361 their mean values, negative residuals being represented by Italics. The next column gives in the same form the residuals found by subtracting the mean photographic magnitudes from the results of the authorities indicated by the letters at the head of the column. When the residual exceeds nine, it is indicated by a **p** if it is positive, and by an **n** if it is negative. The exact value is then given in the notes following the table. At the head of this column the letter *a* denotes the magnitudes found by Lindemann, Mémoires Acad. Imper. St. Pétersbourg, XXXII. No. 6, p. 22; *b*, observations of Pritchard, Monthly Notices Royal Astron. Soc., XLII., p. 227; *c*, observations in Uranometria Oxoniensis, p. 94; and *d*, observations in Harvard Observatory Annals, XIV., p. 398. To correct for the difference in the zero of the scale of these four catalogues, their magnitudes were first corrected by adding the quantities —0.07, —0.15, —0.12, and +0.10, respectively, before subtracting the photographic magnitudes. The sums of the positive and negative residuals for each catalogue were thus made nearly equal. The last column describes the spectrum. A denotes that the character of the spectrum is uncertain, owing to the presence of an adjacent star; F, that the spectrum is too faint to render its character certain, I, that the spectrum belongs to Class I. as described above; R, that the spectrum possesses some peculiarity more fully explained in the remarks following the table. These remarks also indicate which stars interfere when A is entered in the last column, and give additional observations when the first measures are discordant.

TABLE IV.

No.	Designation.	DM.	R. A. 1885.	Dec. 1885.	Magn.	Resid.	*a b c d*	Sp.
			m. *s.*	° ′				
227	25 η Alcyone	+23° 541	40 38.9	+23 44.9	2.70	3 *2* 1 *2*	3 0 3 4	I
66	17 b Electra	+23° 507	38 2.9	23 44.8	3.82	2 *3* 0 2	*2* *2* 0 *1*	I
115	20 c Maia	+23° 516	38 59.0	24 0.7	4.05	0 0 2 0	*1* *3* *2* 0	I
79	19 e Taygeta	+24° 547	38 21.7	24 6.3	4.05	2 0 0 0	2 4 4 5	I
349	27 f Atlas	+23° 557	42 19.4	23 42.1	4.45	1 1 1 *1*	*8* . *6* *6*	I
146	23 d Merope	+23° 522	39 30.1	23 35.3	4.48	2 0 0 *3*	*3* *4* *3* *2*	I
353	28 h Pleione	+23° 558	42 20.6	23 47.1	4.90	*1* 1 1 *1*	3 . 4 3	I
76	18 m	+24° 546	38 18.0	24 28.6	4.95	*2* 0 0 0	4 7 9 8	I
62	16 g Celæno	+23° 505	37 58.1	23 55.6	5.05	0 2 0 0	2 2 2 3	I
121	21 k Asterope	+24° 553	39 3.3	24 11.6	5.52	0 *2* 0 3	1 1 3 4	I
293	28	+22° 563	41 32.7	23 4.0	5.95	*2* 0 0 0	*6* . *3* *4*	I
129	22 l	+24° 556	39 11.8	24 10.0	5.95	0 *2* 0 0	0 2 4 4	I
212	24 p	+23° 536	40 30.8	23 45.5	6.05	3 *2* . .	*1* *4* *1* .	I
182	12	+24° 562	40 8.2	24 9.7	6.32	2 0 *3* 2	1 2 3 4	I
406	34	+23° 563	42 54.3	23 21.6	6.42	*2* 1 1 1	*6* . *3* *2*	I
423	38	+23° 569	43 8.3	23 29.9	6.52	0 0 3 *2*	0 . 2 2	I
105	4	+23° 512	38 47.3	23 58.4	6.52	0 0 *2* 3	3 9 8 .	I
300	29	+23° 553	41 39.1	23 59.5	6.60	*1* *3* 2 2	1 *1* *1* 1	I
370	32	+23° 561	42 30.4	24 1.7	6.62	*1* *1* 4 *1*	*2* . *4* *2*	I
338	26 s	+23° 556	42 7.1	23 30.3	6.70	*2* 1 3 *2*	*7* *4* *3* *2*	R
226	24	+23° 540	40 38.9	23 56.0	6.80	2 *2* 0 0	*5* *5* *4* *2*	A
151	10	+23° 523	39 36.9	23 53.7	6.82	2 0 *3* 2	1 2 2 2	I

TABLE IV.— *Continued.*

No.	Designation.	DM.	R. A. 1885.	Dec. 1885.	Magn.	Resid.	*a b c d*	Sp.
			m. *s.*	° ′				
473	40	+23° 570	44 2.3	+23 36.8	7.02	0 *2* 3 0	*6* . 0 *3*	I
141	8	+23° 519	39 23.6	23 50.1	7.40	1 *1* 1 *1*	*4* *1* *2* .	A
214	20	+24° 566	40 32.5	24 13.9	7.40	1 *1* *1* 1	*3* . 0 0	I
213	19	+23° 537	40 31.8	23 26.8	7.42	1 0 1 *1*	*8* *8* *8* *6*	A
217	22	+23° 538	40 34.9	23 33.5	7.48	0 *1* 0 0	*6* *9* *8* *6*	A
447	39	+24° 578	43 36.5	24 8.7	7.48	0 *1* 0 0	*3* . *3* *3*	R
418	37	+23° 567	43 5.3	23 59.9	7.48	0 *1* 0 0	*2* . *3* *3*	I
365	31	+23° 560	42 25.5	24 2.6	7.52	0 2 0 0	*2* *9* *8* .	I
235	25	+23° 542	40 48.1	23 15.2	—	. . . .	. . . .	A
358	30	+23° 559	42 22.5	23 32.1	7.52	0 3 *2* 0	2 1 2 .	A
208	17	+23° 535	40 28.8	23 22.1	7.55	*1* 2 *1* 2	n n *8* .	I
120	7	+23° 517	39 2.5	23 40.7	7.58	2 *1* *1* *1*	*1* *3* *2* .	I
209	18	+23° 536	40 29.1	23 46.9	7.65	*1* 2 2 *1*	5 2 *2* .	A
192	13	+23° 528	40 14.5	23 38.3	7.78	0 2 0 *3*	2 2 3 .	I
280	27	+23° 549	41 22.7	23 57.8	8.00	0 0 0 0	*1* . . .	R
219	21	+24° 567	40 35.0	24 18.0	7.63	0 2 *1* .	6 3 *2* .	A
376	33	+23° 562	42 35.1	23 53.7	7.70	1 *2* . 1	0 *6* n .	I
91	1	+23° 510	38 36.4	23 40.4	7.70	1 *2* . 1	2 *6* *4* .	I
101	2	+23° 550	38 43.7	24 6.1	7.90	. 1 *2* 1	2 . . .	F
198	14	+23° 530	40 21.3	23 25.4	7.93	1 . *1* 1	9 . . .	F
11	—	+23° 495	36 53.7	24 0.7	7.93	1 *1* . 1	. . . .	I
161	—	+23° 524	39 45.9	23 15.8	8.00	0 0 . 0	. . . .	I
407	35	+23° 564	42 55.2	23 53.6	8.07	1 . *1* *1*	p p p .	F
37	—	+23° 500	37 23.3	24 2.4	8.07	*1* 1 . *1*	. . . .	F
109	6	+23° 513	38 51.1	23 55.6	7.40	. 1 *1* .	p p p .	F
143	9	+23° 520	39 25.7	23 49.8	7.50	0 0 . .	*2* 2 1 .	A
225	23	+23° 539	40 38.1	23 19.3	7.75	. *1* 0 .	*4* *5* *3* .	I
202	15	+23° 531	40 26.6	23 46.3	7.75	*3* 2 . .	5 6 2 .	F
103	3	+23° 511	38 45.7	23 43.3	8.00	. . 0 .	p . . .	F
204	16	+23° 533	40 27.5	23 27.6	8.00	. . . 0	. . . .	F
403	—	+22° 573	42 51.9	22 59.5	8.00	. 0 . .	. . . .	I
415	36	+23° 565	43 3.9	23 52.0	8.20	. 0 . .	8 4 8 .	F
4	—	—	36 40.9	24 17.5	9.00	. 0 . .	. . . .	F
45	—	—	37 33.3	23 8.9	9.00	. . . 0	. . . .	F

REMARKS.

146. Plate 361. A second measure gave 4.5 instead of the original measure 4.0. The mean value 4.2 has been adopted. The original residuals were 3 1 1 *4*.

212. Plates 327 and 361. The trails could not be measured on account of the proximity of 227.

182. Plate 327. A second measure gave 6.0 as before.

300. Plate 327. A second measure gave 6.5 instead of 7.0. The mean value 6.8 has been adopted. The original residuals were *1* *3* 4 2.

370. Plate 327. A second measure gave 7.0 as before.

338. Spectrum Type I, but the K line is as intense as the H line.

226. Plate 248. A second measure gave 7.0 instead of 6.2. The mean value 6.6 has been adopted. The original residuals were 3 *5* 1 1. Spectrum uncertain; 227 interferes.
141. Spectrum probably Type I, but not separated from 143.
213. Spectrum uncertain; 208 interferes.
217. Spectrum uncertain; 227 interferes.
447. Spectrum Type I, but the K line is visible, and about 0.2 as intense as the H line.
235. 227 interferes.
358. Plate 209. A second measure gave 7.0, but a more careful estimate gave 7.5 instead of the original measure 8.0. The mean value 7.5 has been adopted. The original residuals were 4 2 *3* 1. Spectrum uncertain; 349 interferes.
208. Residuals in *a*, *11*; in *b*, *10*.
120. Spectrum Type I. Presence of K line doubtful on account of interference of 115.
209. Spectrum uncertain; 212 interferes.
192. Spectrum Type I, but too faint to decide whether the K line is present.
280. Spectrum faint; lines narrow, if present.
219. Spectrum uncertain; 214 interferes.
376. Residual in *c*, *10*.
101. Spectrum not seen; 105 and 115 interfere.
198. Spectrum not seen; 213 and 217 interfere.
11. Spectrum faint.
407. Residuals in *a*, 12; in *b*, 14; in *c*, 15.
109. Spectrum not seen; 105 interferes. Residuals in *a*, 16; in *b*, 17; in *c*, 18.
143. Spectrum probably Type I, but not separated from 141.
202. Spectrum not seen; 212 interferes.
103. Spectrum not seen; 105 interferes. Residual in *a*, 12.
204. Spectrum not seen; 213 and 217 interfere.

The spectra of Nos. 169 and 245 were seen, but were too faint to indicate their type. No trails were given by the stars 26, 11, and 5 *Pleiadum*, which have the numbers 245, 169, and 107 in Wolf's Catalogue.

An important inference may be drawn from the comparison of the spectra of the stars of this group. It is extremely improbable that chance alone has brought together so many bright stars in the same portion of the heavens. Most of them probably have a common origin, and are much nearer to each other than to the Solar System. A few, doubtless, have only an apparent connection with the group, their real distance being much greater or less than that of the others. Ordinary means fail to distinguish the individuals of these two classes. The similarity in the chemical and physical conditions indicated by the apparent identity of most of the spectra, is a strong confirmation of their common origin. The variation in the spectra of such stars as Nos. 338 and 447 seems to indicate that these stars happen to lie in the same direction from us as the others, but are not really connected with them. In a study of the parallax of the Pleiades, it seems very desirable that these stars also should be observed.

To determine the probable error of a single determination of brightness, those stars only should be included which are measured on all four plates. The original uncorrected residuals are also used even in those cases where a second measure showed that the first estimate was erroneous. The 140 residuals of the 35 stars included in this list give an average deviation of ±0.119 magnitudes. Using the corrected residuals, the average deviation would be reduced to ±0.106. The probable error of a single estimate will be 0.119 × 0.976, or ±0.12, and the error of a single star ±0.06. Of the residuals, 47 have the value 0; and of the positive residuals, 23, 15, 8, and 3 have the values +0.1, +0.2, +0.3, and +0.4, respectively. Of the negative residuals, 23, 13, 5, 2, and 1 have the values —0.1, —0.2, —0.3, —0.4, and —0.5. An examination of the entire number of 163 estimates showed that the frequency with which the various tenths of a magnitude were employed varied greatly; the figure 5 occurred 61 times; 0, 47 times; 8, 33 times; 3, 15 times; 2, 7 times; 4, 5 times; 7, 4 times; 6, once; 1 and 9, not at all. A test of the relative sensitiveness of the plates is afforded from the average value of the residuals relating to the images contained on each. The means for Plates 209, 248, 327, and 361, are +0.046, —0.040, +0.031, and —0.009. Accordingly, the stars on Plate 209 appear on the average about one twentieth of a magnitude fainter than on the average of the four plates. These corrections are so small that it is hardly necessary to apply them.

Measures were made of the positions of the images on Plate 327, to determine the degree of precision to be expected from the application of photography to transit instruments. The shortest exposures do not seem to have been much less than a second, owing to the time required to cover and uncover the glass. The images formed by the shorter exposures were minute circular dots, which for the fainter stars did not exceed 0.008 cm. in diameter. They were not perfectly symmetrical, probably owing to the diffraction when the lens was nearly covered. All the stars were, however, subjected to the same conditions. About a dozen of the brighter stars formed images even with the shortest exposures. The intervals between these images were measured by attaching the photograph to a micrometer-screw having a pitch of one twenty-fourth of an inch, by which it could be moved across the field of a microscope. The magnifying power was only ten diameters, and could doubtless have been increased with advantage. Eight settings were made on each star, seven on the centre of the dots formed by the exposures of two seconds, of one second, and of half a second, and one on the end of the last trail. Nine stars were measured in this way, and the first of them was taken a second time to see if the instrument had moved. The intervals were next found by taking the first differences of these readings. The means of the ten values of these seven intervals, expressed in revolutions of the micrometer-screw, were 0.380, 0.230, 0.139, 0.353, 0.145, 0.142, and 0.497. Each revolution is equivalent to $13^s.87$. The residuals found by subtracting these mean values from the observed intervals are given in Table V., expressed in seconds of time. As in Table IV., the first column serves to designate the star by its number in the Catalogue of Wolf.

TABLE V.

No.	Designation.	Residuals.						
		I.	II.	III.	IV.	V.	VI.	VII.
		s.	s.	s.	s.	s.	s.	s.
349	Atlas	+0.06	+0.07	−0.03	−0.03	−0.01	0.00	+0.01
353	Pleione	0.00	+0.02	−0.03	−0.04	+0.10	+0.01	−0.06
146	Merope	+0.10	−0.04	−0.04	−0.01	+0.07	−0.03	+0.10
66	Electra	0.00	−0.06	+0.03	+0.08	−0.03	+0.04	0.00
62	Celæno	−0.13	−0.01	+0.13	+0.01	+0.04	−0.11	+0.03
115	Maia	+0.06	+0.03	−0.08	+0.01	−0.04	+0.04	+0.03
79	Taygeta	−0.21	+0.07	−0.01	−0.04	−0.01	+0.07	−0.14
121	Asterope	+0.11	−0.17	+0.10	−0.01	+0.01	−0.08	−0.07
227	Alcyone	+0.14	+0.03	−0.06	+0.03	−0.10	+0.08	+0.11
349	Atlas	−0.06	+0.01	0.00	+0.03	−0.03	+0.01	−0.04

The average values of these residuals, taken without regard to sign, are 0.087, 0.051, 0.051, 0.029, 0.044, 0.047, and 0.059, in the seven columns respectively. The first of these values is decidedly greater, showing that it was difficult to set with accuracy on the centre of so long a line as that produced when the exposure lasted for two seconds. The last value is also somewhat greater, owing to the difficulty of determining the end of a trail. The difference is, however, much less than was anticipated. The mean of all the residuals is 0.053, or, if we use only the intervals between short exposures and reject the first and last values, 0.044. Since all of these values are found from the difference of two settings, we must divide by the square root of two to obtain the average deviation of a single setting. We thus obtain the values 0.037 and 0.031. The probable error of a single setting is found by multiplying these values by 0.85, which gives ±0.031 and ±0.026. No setting has been rejected for discordance, and no change made in the original record except that the seventh setting on Maia was recorded 54.685 and was assumed to mean 54.635. This setting 54.685 would render the preceding and following values so large that they would have to be rejected for discordance. One would be increased and the other diminished by $0^s.70$. As shown in the Table, the assumed value gives the residuals $+0^s.04$ and $+0^s.03$. To show how far the deviations were due to errors of setting, ten successive settings were made on a single image of Celæno, and gave an average deviation of $\pm 0^s.015$ and a probable error of $\pm 0^s.013$. These various values could doubtless be reduced by the use of a higher magnifying power, that employed being much too low. The probable error of a transit over a single wire by the usual method may be taken as $\pm 0^s.06$. The above measures show that the probable error of a single setting on the images of different stars is not far from one half of this, $\pm 0^s.03$. The probable error of successive settings on the same image is only $\pm 0^s.015$. The observations on different stars seem fairly to represent the accuracy to be expected in determining the position of stars by photography from transit observations. Besides errors of setting, there are included in the quantity above mentioned, $0^s.03$, those due to lack of symmetry of the images, variation in the brightness of the stars, unequal expansion or irregularities in the film, so far as these could affect measures over small distances, and the various errors in the measuring instrument. Many of these quantities can doubtless be greatly diminished, but the results already obtained seem to prove the possibility of measuring the position of stars photographically from their transits, with an accuracy at least equal to that obtained in the usual manner.

Close Polar Stars.

A large number of photographs were taken of the vicinity of the north pole. Some of these were made when the telescope was at rest, the stars leaving trails; others, principally intended for testing the position of the polar axis, were made with the telescope driven by the clock. The number of stars on each plate may be inferred from the fact that over one hundred stars within one degree of the pole leave trails when the telescope is at rest. As each photograph extends five degrees from the pole, the complete reduction would be very laborious. The photographic brightness of the stars within one degree of the pole has been measured on three of the plates, Nos. 7, 21, and 231. The method of measurement was the same as that employed for the Pleiades and described on page 211. The attention of the observer, Miss Farrar, was called to the preponderance, in the estimates of the light of the Pleiades, of the zero tenths and five tenths of a magnitude, and this difficulty is corrected in the present measures. Plate 7 was taken on August 8, 1885, and had an exposure of 70 minutes; Plate 21 was taken on September 3, 1885, with an exposure of 165 minutes, and Plate 231 was taken on December 24, 1885, with an exposure of 50 minutes. The accordance of the measures is very satisfactory. The total number of stars is 117, and of the separate measures 330. The average value of the residuals found by subtracting the mean value of the brightness of each star from the separate values, expressed in magnitude, is 0.088. Accordingly, single measures of photographs taken on different nights will differ on the average by less than a tenth of a magnitude. It is doubtful if this degree of accuracy can be attained by any other photometric process hitherto employed. In no case does a residual exceed three tenths of a magnitude, and in one case only do the measures of the same star differ from one another by as much as six tenths of a magnitude. The greater portion of these stars are too faint to be contained in existing catalogues. Their positions have not yet been determined from the photographs. A full publication of their magnitudes does not therefore seem desirable in the present Memoir. As examples, the 38 stars enumerated in the Durchmusterung as belonging to this region have been selected from the entire list of 117 stars, and their measurements are given in Table VI. The successive columns give the Durchmusterung numbers, the photographic brightness of the trail, and the residuals from the mean expressed in tenths of a magnitude, negative residuals being indicated by Italics. In order to make the magnitudes correspond with those of equatorial stars giving trails of equal intensity, each of the original readings has been diminished by three magnitudes. By means of Table II. and the formulas given on page 190, a correction has been applied for the declination of

TABLE VI.

No.	Trail.	Resid.	Magn.	DM.	Res.	No.	Trail.	Resid.	Magn.	DM.	Res.
1	4.00	1 *1* 0	10.1	9.5	5	20	6.30	1 1 *2*	11.0	9.5	*4*
2	5.60	0 *1* 0	10.2	9.2	*2*	21	4.00	0 0 0	8.8	8.8	4
3	3.53	0 3 *2*	9.0	8.8	2	22	5.03	*1* 2 0	9.3	8.7	*3*
4	5.20	1 1 *2*	10.4	9.4	0	23	6.00	0 0 0	10.9	9.4	*5*
5	6.40	*1* 0 1	11.3	9.5	—	24	6.50	0 0 0	11.3	9.5	7
	6.40	*1* 0 1	11.3		—	25	3.93	0 0 1	9.1	9.0	5
6	5.63	0 3 *2*	10.2	9.4	2	26	4.87	0 *1* 0	10.9	9.5	*3*
7	4.77	*3* 2 0	9.4	9.3	8	27	6.27	*1* 1 *1*	10.6	9.5	0
8	6.70	*1* 1 0	11.5	9.5	*9*	28	5.17	2 *1* *2*	9.7	8.7	7
9	4.93	1 *1* 1	10.0	9.1	*2*	29	4.27	*3* 0 2	9.9	9.4	5
10	5.80	*1* 1 0	10.3	9.5	3	30	5.43	2 0 *1*	10.0	9.3	2
11	6.03	0 1 0	10.4	9.5	2	31	5.57	*2* 1 0	11.2	9.5	*6*
12	4.70	*1* 1 0	10.0	9.1	*2*	32	5.70	2 0 *2*	10.4	9.5	2
13	2.77	*3* 1 1	7.1	7.0	—	33	4.93	3 0 *2*	10.1	9.5	5
14	6.27	0 *1* 0	10.6	9.5	0	34	5.60	2 0 *2*	10.4	9.3	*2*
15	5.47	*1* 1 *1*	9.8	9.2	2	35	4.67	*1* 0 *1*	10.8	9.3	*6*
16	6.13	0 1 0	11.1	9.5	*5*	36	4.27	*3* 0 2	9.8	9.5	8
17	4.23	*1* 2 0	9.1	9.0	5	37	3.93	1 *1* 1	11.0	9.3	*8*
18	4.33	*3* 1 3	9.6	8.9	*2*	38	4.77	0 *1* 0	9.4	9.0	2
19	5.77	1 *1* *1*	10.7	9.5	*1*						

the star. The result, which is given in the fourth column, shows the actual photographic brightness of these stars. The fifth column gives the Durchmusterung magnitude, and the final column gives the residual found by subtracting the photographic from the DM. magnitudes, after reducing the scale of the latter to that of the former. Positive residuals indicate stars of a bluish color, and negative residuals those of a reddish color, provided no errors are present.

No. 5, or DM. +89° 5, is shown to consist of two equal stars, whose combined light would equal that of a star of the magnitude 10.6, and give a residual zero in the last column. Nos. 14 and 15 are so nearly in the same declination that their trails coalesce, although separate at the ends. Their combined light was originally measured, and the measures given were made subsequently. No. 27 was originally omitted, since by precession it is now outside of the limit of one degree north polar distance.

The greater portion of the stars in Table VI. differ but little in brightness. Accordingly, measurements were made of the polar stars proposed as standards of

TABLE VII.

Desig.	α 1880.	δ 1880.	Trail.	Resid.	Photog. Magn.	Photom. Magn.	Res.
	h. m.	° ′					
88° 8	1 14	88 40	—	. . .	—	2.2	—
86° 269	18 11	86 37	1.17	*2* 1 0	4.4	4.3	*1*
87° 51	6 44	87 14	2.40	*2* 1 1	5.7	5.3	*4*
88° 112	19 44	88 57	3.43	1 *1* 1	7.8	6.5	n
88° 4	0 51	88 23	3.08	*1* 1 1	6.8	7.0	2
88° 9	2 3	88 36	3.97	0 0 *1*	8.1	8.6	5
89° 3	2 28	89 36	3.37	*1* 1 *1*	8.9	9.2	3
89° 35	17 50	89 48	4.33	1 0 0	10.4	9.8	*6*
88° 37	19 28	89 54	3.67	1 *1* *1*	10.8	10.5	*3*
89° 1	0 19	89 45	3.87	*1* 1 *1*	10.0	10.5	5
89° 26	13 23	89 49	5.13	2 0 *1*	11.1	10.6	*5*
a	19 30	89 54	6.00	0 0 0	12.9	12.2	*7*
b	19 30	89 55	5.93	1 1 *1*	13.0	12.4	*6*
h	22 0	89 50	6.23	2 1 *2*	13.2	12.8	*4*
k	23 10	89 53	6.13	1 *1* 1	12.7	13.2	5
d	14 0	89 57	—	. . .	—	13.3	.
l	0 0	89 54	—	. . .	—	14.0	.
c	18 30	89 58	6.60	2 0 *1*	14.2	14.0	*2*
e	9 10	89 58	—	. . .	—	14.8	.
f	3 4	89 58	—	. . .	—	14.8	.
g	0 10	89 57	—	. . .	—	15.7	.

brightness in the Proceedings of the American Association, XXXIII. 8. Their designations, right ascensions and declinations for 1880, and photometric magnitudes, are estimated from that publication, and are given in the first, second, third, and seventh columns of Table VII. The mean magnitudes of the photographic trails are given in the fourth column, and the residuals in the fifth column. The sixth column gives the magnitude corrected for declination, and the last column gives the photometric minus the photographic magnitudes. Positive residuals indicate blue, and negative, red stars. The first four stars are α *Ursæ Minoris,* δ *Ursæ Minoris,* 51 *Cephei,* and λ *Ursæ Minoris.* The trail of the first of these is too intense to be measured.

A second reading of the trail of h, Plate 231, gave 9.3 instead of 8.8. The mean value 9.0 has been adopted. The original residuals were 2 1 *4*. The red color of λ *Ursæ Minoris* is indicated by the large negative residual, the value of which is *13*.

The readiest method of publishing the results obtained by any photographic process is to reproduce them so far as possible in paper prints obtained exclusively by photographic means from the original negatives. In such prints, however, as is well known, many of the details of the negatives cannot be traced, and an unfavorable impression of the value of the work may thus be occasioned. On the other hand, if every detail which may be detected in a negative is described, or reproduced by engraving, the original may be supposed to be far superior to other photographs of nearly the same actual value. In the present case, no attempt at an exhaustive study of the negatives has yet been made. What is here described may be seen upon them with little difficulty.

Plate II. represents the central portion of photograph No. 6, taken on August 6, 1885, with an exposure of 72 minutes, and enlarged five times. It therefore represents the portion of the sky within about one degree of the pole. The scale is five times that of the Durchmusterung, one degree equalling 10 cm. The stars contained in the Durchmusterung zone +89° are here designated by their numbers in that Catalogue. The designations of the other stars proposed as standards of magnitude for faint polar stars, and given in Table VII., are also inserted. The trails left by the stars are untouched, although, owing to the defects of the photolithographic process, they are very irregular. In the original they form perfectly smooth lines. The Pole-star appears as a broad band in the left-hand lower corner. The Voigtländer No. 4 lens, described on page 183, gave nearly as many stars as the larger lens afterwards employed. DM. +89° 37, magnitude 10.5, was always well shown, and under favorable circumstances star b, magnitude 12.4, was distinctly seen. With the eight-inch lens DM. +89° 37 and a were distinctly separated in the original negative. This is a satisfactory proof of the good definition of a lens of so short a focus.

MISCELLANEOUS.

The different photometric processes which have been used in determining the light of the stars give results which differ systematically when large variations in light are to be measured. In the Harvard Observatory Annals, Vol. XIV. p. 504, it is shown that the systematic variations of the best catalogues exceed one fifth of the entire intervals measured. In other words, if a great number of pairs of stars are selected, whose average difference in brightness is five magnitudes according to one catalogue, the difference will be only four magnitudes in another. This is also true when the logarithms of the light are used. It is not due to a difference in the assumed value of the unit of the scale of magnitudes, but to an actual difference in the measurement of the amount of light. In the case assumed above, if the light of the brighter star is taken as 100, that of the fainter star according to one catalogue will be 1; according to the other, it will be 2.5. Evidently, large errors affect one or more of the catalogues compared, which cannot be eliminated by increasing the number of observations. The best way of determining which is probably correct is to repeat the measures by a variety of entirely different methods. Photography affords an excellent means of doing this, since the errors, if any, will be of a very different kind. Several methods may be employed, each giving an independent test. The construction of a standard scale, as described on page 211, gives a direct measure of the ratio of the light of two stars of the same color, if we can assume that the brightness of the image is proportional to the area of the object-glass. The principal objection to this method arises from diffraction, which enlarges the images when the aperture is very small. A defect in the portion of the plate on which the standard is photographed might affect all of the measures. This should be tested by measuring all the stars on a plate which has received several exposures with various apertures. The results also give a good means of studying the effect of aberration at different distances from the centre of the plate. Instead of varying the aperture, we may vary the time of exposure. This may be accomplished by varying the rate of motion of the image. For stars in the vicinity of the pole, the velocity is proportional to the polar distance. If, as on page 187, we assume that the brightness of a star capable of producing a given impression will vary as the

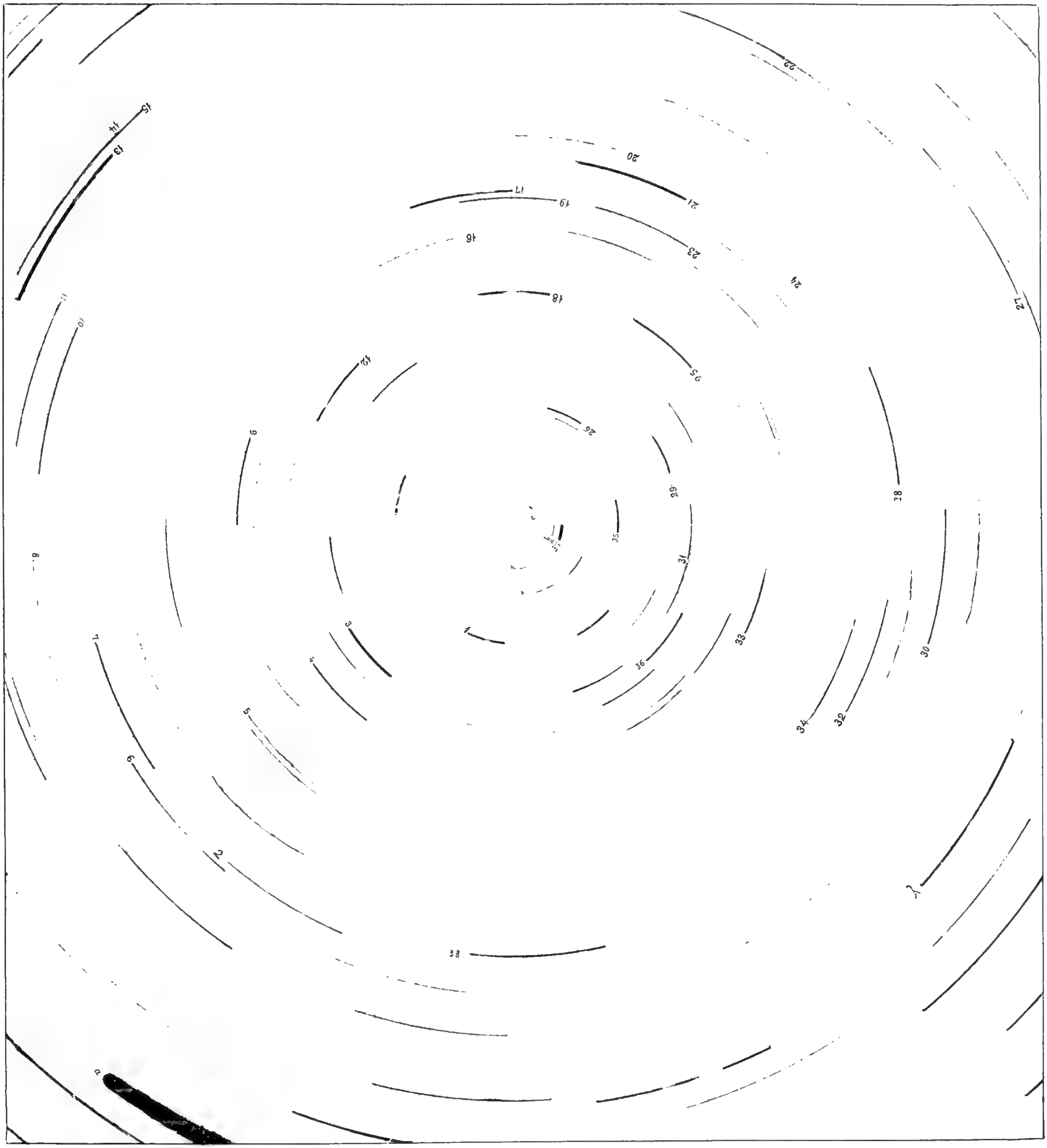


Plate 2

1° = 10 cm.

— TRAILS OF CIRCUMPOLAR STARS. —

time of exposure, we may hence obtain a method of determining relative intensities of light. If two stars give equally distinct trails, their intensities must be inversely as their polar distances. The last column in Table VII. shows that this condition is nearly fulfilled. The difference in the photographic magnitude of 86° 269 and c is 9.8 magnitudes, and the photometric difference is 9.7 magnitudes. The image of the first star in this case moves nearly seventy times as fast as the image of the second star. Individual stars show a greater discordance, but the entire series fails to indicate any appreciable systematic variation. The evidence is not conclusive, on account of the small number of stars and the color of some of them. A much better test is afforded by Plate 245. This photograph was taken on January 5, 1886. Two exposures were made of the vicinity of the north pole. The first was made with the clock attached, but the axis was so far out of adjustment that the resulting elongation of the images caused them to appear as trails of a considerable length. The second exposure was made without clockwork. All the trails during the first exposure had the same length, whatever the position of the stars. The trails formed during the second exposure had a length proportional to their polar distance. Accordingly, for stars near the pole the second trail was much the most intense, while the opposite effect was produced for the more distant stars. A discussion of the relative intensity of the trails of all these stars affords an additional determination of the light ratio corresponding to one magnitude. Plate 238, taken on December 30, 1885, was made in a similar way. Another determination might be made by varying the velocity of the images. This could be done by changing the rate of the clock, or the position of the polar axis.

The above methods depend on observations of trails. Similar processes may be applied to the images formed with clockwork, when the instrument and the clock are accurately adjusted. A scale for comparison may be made by taking a series of photographs with different apertures, or varying the time of exposure, moving the telescope a little in right ascension or declination between successive exposures. Two such exposures may be made on the plate to be measured, and the images compared by the method employed by Argelander for observing variable stars. Each image will thus be compared with others of nearly equal brightness, and the final values in grades may be reduced to ratios of light by the relative times or apertures employed in the two exposures. Plate 209, described on page 210, may be reduced in this way. Two exposures were made, of one and five minutes respectively, so that the brighter image of each star represents five times the intensity of the fainter image. Plate 375, taken on February 22, 1886, can be used in the same way. It represents the Nebula of Orion, with exposures of 16^m, 8^m, 4^m, 2^m, 1^m, 30^s, and 15^s. Besides measuring the relative brightness of the stars, this plate permits the relative intensity of different portions of the nebula to be measured. Similar results were obtained on Plates 368, 372, 374, and 382.

The large angular aperture of the lens employed is especially advantageous in photographing the fainter portions of this nebula. An exposure of about 5^m gives the best image of the central portions of the nebula. With 15^m the central portion is completely burned out, and the nebula has as great an extent as is shown in the beautiful photograph obtained by Mr. Common on January 30, 1883. This photograph was taken with the 36-inch reflector, and had an exposure of 39 minutes. The images of the stars in Mr. Common's photograph, owing to the greater focal length of the telescope, are much smaller and better defined than in the Cambridge photographs. The latter, with an exposure of an hour, gives an extension to the nebula of about a square degree. The nebulosity around c *Orionis* is shown with much detail in these photographs.

The nebulosity around the star Maia in the Pleiades, discovered by MM. Henry, was confirmed by Plate 104, taken on November 3, 1885. Although this nebulosity was at once recognized, it was ascribed to a defect in the plate until the true explanation was given by MM. Henry. The first photograph of this object by these gentlemen was taken thirteen days later, or on November 16, 1885.

Jupiter's satellites, as might be expected from their brightness, gave well-marked trails when the telescope was at rest. Some experiments were accordingly made to determine whether the times of the eclipses of the satellites could be advantageously observed by photography. Were it not for the presence of the planet, this would probably be the most accurate method of determining these times, employing the method described on page 211. When the telescope was driven by clockwork, good images of the satellites were obtained in two seconds, and the images were overexposed when the exposure much exceeded ten seconds. During an eclipse the experiment was tried of making a series of exposures, each lasting for ten seconds, at regular intervals of fifteen seconds. The telescope was moved a short distance in right ascension or declination after each exposure, and during the five seconds preceding the usual exposure. Excellent images of the more remote satellites were obtained, but, owing to the short focal length of the telescope, the image of the satellite undergoing eclipse was obscured by that of Jupiter, which was large, on account of the length of the exposure.

CONCLUSIONS.

The work in stellar photography done at the Harvard College Observatory may be summarized as follows. The first stellar photograph ever taken was obtained here in 1850. In 1857 the investigation was resumed, and the value of stellar photography as a means of determining the positions and brightness of the components of double stars was established. In 1882, the present research was undertaken with a lens having an aperture of only 2½ inches. It was shown that photography could be used as a means of forming charts of large portions of the sky, and of determining the light and color of stars in all portions of the heavens. Photographs of the trails of close polar stars no brighter than the eleventh magnitude were obtained without clockwork. Stellar spectra were obtained of the brighter stars without clockwork, in which all the principal lines were well shown. In 1885 the investigation was resumed with a telescope having an aperture of 8 inches. With this, 117 stars within one degree of the pole, one of them no brighter than the fourteenth magnitude, left trails. The average deviation of the measures of the brightness of these stars on different photographs was less than a tenth of a magnitude, a greater accordance than is given by any other photographic method. A similar result was obtained from the Pleiades, of which group over fifty left trails. Similar trails are now being obtained of the stars north of —30° in all right ascensions. This work began in the autumn of 1885 at 23^h, and has already been completed for more than half of the sky. By photographing on the same plate polar stars near their upper and lower culminations, material has been accumulated for determining the atmospheric absorption on each night of observation. A study has been made of the application of photography to the transit instrument. Measurements of the trails show that the position of a star may be determined from its trail with an average deviation of $0^s.03$, which is about one half the corresponding deviation of eye observations.

Charts may be constructed 5° square, having the same scale and dimensions as those of Peters and Chacornac. A single exposure of one hour is required, and it is not necessary that the observer should remain with his eye at the telescope to correct the errors of the clock.

By placing a large prism in front of the object-glass, excellent stellar spectra have been obtained. An exposure of five minutes gives the spectra of all stars brighter than the sixth magnitude in a region 10° square. About half of the region north of —25°, beginning at $0^h\ 0^m$, has been photographed in this way. With an exposure of an hour the spectra of stars no brighter than the ninth magnitude are shown. Over a hundred stars have thus been taken simultaneously on a plate by a single exposure. Means have been provided for carrying out this work on an extended scale, as a memorial to the late Dr. Henry Draper.

Miscellaneous observations have been secured of the Pleiades, of the Nebula in Orion, of Jupiter's satellites, and of various other objects; also of the new star in Orion and of its spectrum, and one plate showing that this star must have been much fainter on November 9, 1885, than when discovered, five weeks later.

MEMOIRS

OF

THE AMERICAN ACADEMY

OF

ARTS AND SCIENCES.

MDCCLXXX.

CENTENNIAL VOLUME.

Vol. XI.—Part IV.—No. V.

CAMBRIDGE:
JOHN WILSON AND SON.
University Press.
1886.

V.

A Catalogue of 130 Polar Stars for the Epoch of 1875.0, resulting from all the available Observations made between 1860 and 1885, and reduced to the System of the Catalogue of Publication XIV. of the Astronomische Gesellschaft.

By WILLIAM A. ROGERS and ANNA WINLOCK.

Presented June 16, 1886.

FIRST PAPER.

Note by William A. Rogers. — My connection with this work is limited to the methods of discussion adopted, and to an examination of the numerical results obtained. Beyond this, all the work in the preparation of this paper has been done by my assistant, Miss Winlock, and she is entitled to all the credit therefor.

It is the purpose of the present paper to discuss the modern observations of such polar stars north of +70° declination as are found in the Harvard College Catalogue of 1213 Stars. Of the 130 stars in this list, 68 are found in the Fundamental Catalogue of Dr. Auwers.

There will be no attempt to determine the proper motions of these stars, but the places determined for the epoch 1875.0 will serve a useful purpose in future discussions of this element. The provisional values of μ and μ' employed in the reductions are those given in the Harvard College Catalogue.

All the observations employed in this discussion will be reduced to the System of Publication XIV. of the Astronomische Gesellschaft, either directly through the medium of the fundamental stars common to the observed and the fundamental systems, or indirectly through the medium of the Harvard College Catalogue.

For many reasons, it was found advisable to construct a yearly ephemeris of each of the stars in the proposed list, extending from 1860 to 1885. For the fundamental stars of the list, the places for 1880 and for subsequent years were taken directly either from the catalogues of the Astronomische Gesellschaft or from the

Berliner Jahrbuch. For the years 1871 to 1879 inclusive, they were obtained by applying to the yearly ephemerides of the Gesellschaft the corresponding corrections by which the provisional system is reduced to the system of Publication XIV.

For the places of the fundamental stars between 1860 and 1870, and for the places of all non-fundamental stars for the entire period between 1860 and 1885, the reduction-elements given in the Harvard College Catalogue were employed.

For stars below 85° north declination the development of α and δ in terms of the first, second, and third powers of the time will be sufficiently accurate for the limit of fifteen years. For the reduction of stars near the pole, the problem becomes more difficult. Since the method of development by differential coefficients in terms of the ascending powers of the time has necessary limitations in its application, it has been thought advisable to give an illustration of the various methods by which the co-ordinates for any time t_0 are reduced to those for any time t'. The star Groombridge 1119 is selected for this purpose. The reductions for precession and for proper motion will be considered independently.

Reduction of the Right Ascension and the Declination for the Equator and Equinox of any Time t_0 to the Values for any Time t' by the Trigonometrical Method of Bohnenberger.

From Bessel's Tabulæ Regiomontanæ, pp. vii, viii, we have

$$\left.\begin{aligned}\cos\delta'\sin(\alpha'+\lambda'-z') &= \cos\delta\sin(\alpha+\lambda+z)\\ \cos\delta'\cos(\alpha'+\lambda'-z') &= \cos\delta\cos(\alpha+\lambda+z)\cos\theta-\sin\delta\sin\theta\\ \sin\delta' &= \cos\delta\cos(\alpha+\lambda+z)\sin\theta+\sin\delta\cos\theta\end{aligned}\right\} \tag{1}$$

Writing for brevity

$$A=\alpha+\lambda+z, \qquad A'=\alpha'+\lambda'-z',$$

we have

$$\left.\begin{aligned}\cos\delta'\sin A' &= \cos\delta\sin A\\ \cos\delta'\cos A' &= \cos\delta\cos A\cos\theta-\sin\delta\sin\theta\\ \sin\delta' &= \cos\delta\cos A\sin\theta+\sin\delta\cos\theta\end{aligned}\right\} \tag{2}$$

From the first two equations of (2) we obtain

$$\left.\begin{aligned}\cos\delta'\sin(A'-A) &= \cos\delta\sin A\sin\theta\,[\tan\delta+\tan\tfrac{1}{2}\theta\cos A]\\ \cos\delta'\cos(A'-A) &= \cos\delta-\cos\delta\cos A\sin\theta\,[\tan\delta+\tan\tfrac{1}{2}\theta\cos A]\end{aligned}\right\} \tag{3}$$

If we put

$$p=\sin\theta\,[\tan\delta+\tan\tfrac{1}{2}\theta\cos A],$$

we have

$$\tan(A'-A)=\frac{p\sin A}{1-p\cos A}, \tag{4}$$

and

$$\tan\tfrac{1}{2}(\delta'-\delta)=\tan\tfrac{1}{2}\theta\,\frac{\cos\frac{1}{2}(A'+A)}{\cos\frac{1}{2}(A'-A)}. \tag{5}$$

Encke has suggested a form of equation (4) which is well adapted for logarithmic computation. (See Danckwortt, Vierteljahrsschrift der Astronomischen Gesellschaft, XVI., 1881, p. 10.)

Let

$$\begin{aligned} m \sin M &= \sin \delta, \\ m \cos M &= \cos \delta \cos A, \end{aligned}$$

whence

$$\tan M = \frac{\tan \delta}{\cos A}.$$

Substituting in (2) we have

$$\begin{aligned} \cos \delta' \sin A' &= \cos \delta \sin A, \\ \cos \delta' \cos A' &= m \cos (M + \theta), \\ \sin \delta' &= m \sin (M + \theta), \end{aligned}$$

whence

$$\left.\begin{aligned} \tan A' &= \frac{\tan A \cos M}{\cos (M + \theta)} \\ \tan \delta' &= \tan (M + \theta) \cos A' \end{aligned}\right\} \qquad (6)$$

Then

$$\alpha' = A' + (z' - \lambda').$$

For the computation of the quantities z, z', and θ, we have the following general equations (see Chauvenet, Vol. I. p. 613):

$$\left.\begin{aligned} \cos \tfrac{1}{2}\theta \sin \tfrac{1}{2}(z' + z) &= \sin \tfrac{1}{2}(\psi' - \psi) \cos \tfrac{1}{2}(\varepsilon_1' + \varepsilon_1) \\ \cos \tfrac{1}{2}\theta \cos \tfrac{1}{2}(z' + z) &= \cos \tfrac{1}{2}(\psi' - \psi) \cos \tfrac{1}{2}(\varepsilon_1' - \varepsilon_1) \\ \sin \tfrac{1}{2}\theta \sin \tfrac{1}{2}(z' - z) &= \cos \tfrac{1}{2}(\psi' - \psi) \sin \tfrac{1}{2}(\varepsilon_1' - \varepsilon_1) \\ \sin' \tfrac{1}{2}\theta \cos \tfrac{1}{2}(z' - z) &= \sin \tfrac{1}{2}(\psi' - \psi) \sin \tfrac{1}{2}(\varepsilon_1' + \varepsilon_1) \end{aligned}\right\} \qquad (7)$$

whence

$$\left.\begin{aligned} \tan \tfrac{1}{2}(z' + z) &= \tan \tfrac{1}{2}(\psi' - \psi) \cos \tfrac{1}{2}(\varepsilon_1' + \varepsilon_1) \\ \tfrac{1}{2}(z' - z) &= \frac{\tfrac{1}{2}(\varepsilon_1' - \varepsilon_1)}{\tan \tfrac{1}{2}(\psi' - \psi) \sin \tfrac{1}{2}(\varepsilon_1' + \varepsilon_1)} \\ \sin \tfrac{1}{2}\theta &= \sin \tfrac{1}{2}(\psi' - \psi) \sin \tfrac{1}{2}(\varepsilon_1' + \varepsilon_1) \end{aligned}\right\} \qquad (8)$$

In which the constants of Struve and Peters for the epoch 1800 are to be employed. They are as follows:

$$\varepsilon_0 = \overset{\circ}{23}\ \overset{\prime}{27}\ \overset{\prime\prime}{54}.22$$

$$\varepsilon_1 = \varepsilon_0 + \overset{\prime\prime}{0}.00000735\, t^2$$

$$\varepsilon = \varepsilon_0 - \overset{\prime\prime}{0}.4738\, t - \overset{\prime\prime}{0}.0000014\, t^2$$

$$\lambda = \overset{\prime\prime}{0}.15119\, t - \overset{\prime\prime}{0}.00024186\, t^2$$

$$\psi = \overset{\prime\prime}{50}.3798\, t - \overset{\prime\prime}{0}.0001084\, t^2$$

COMPUTATION OF $z' - \lambda'$, $z + \lambda$, AND θ, FOR 1867 AND FOR 1883.

	1867.		1875.		1883.
t	+67		+75		+83
$\log t$	1.8260748		1.8750613		1.9190781
$\log t^2$	3.6521496		3.7501226		3.8381562
	° ′ ″		° ′ ″		° ′ ″
ε_0	23 27 54.220000		23 27 54.220000		23 27 54.220000
$+.00000735\,t^2$	+.032994		+.041344		+.050634
ε_1'	23 27 54.252994	ε_1	23 27 54.261344	ε_1'	23 27 54.270634
$50.3798\,t$	0 56 15.4466		1 2 58.4850		1 9 41.5234
$-.0001084\,t^2$	−.4866		−.6097		− .7468
ψ'	0 56 14.9600	ψ	1 2 57.8753	ψ'	1 9 40.7766
$+.15119\,t$	+10.1297		+11.3392		+12.5487
$-.00024186\,t^2$	− 1.0857		− 1.3605		− 1.6662
λ'	+ 9.0440	λ	+ 9.9787	λ'	+10.8825

	For 1867.	For 1883.
	° ′ ″	° ′ ″
$\frac{1}{2}(\psi' - \psi)$	−0 3 21.4576	+0 3 21.4506
$\frac{1}{2}(\varepsilon_1' + \varepsilon)$	23 27 54.2572	23 27 54.2660
$\frac{1}{2}(\varepsilon_1' - \varepsilon_1)$	−0.004175	+0.004645
(1) $\log\sin\frac{1}{2}(\psi' - \psi)$	6.9897585n	6.9897434
(2) $\log\tan\frac{1}{2}(\psi' - \psi)$	6.9897587n	6.9897436
(3) $\log\sin\frac{1}{2}(\varepsilon_1' + \varepsilon_1)$	9.6000903	9.600903
(4) $\log\cos\frac{1}{2}(\varepsilon_1' + \varepsilon_1)$	9.9625128	9.9625128
(2) + (4) = $\log\tan\frac{1}{2}(z' + z)$	6.9522715n	6.9522564
(5) = $\log\frac{1}{2}(\varepsilon_1' - \varepsilon_1)$	7.6206565n	7.6669857
(6) = (2) + (3)	6.5898490n	6.5898339
(5) − (6) = $\log\frac{1}{2}(z' - z)$	1.0308075	1.0771518
	° ′ ″	° ′ ″
$\frac{1}{2}(z' + z)$	−0 3 4.7972	+0 3 4.7908
$\frac{1}{2}(z' - z)$	+10.7351	+11.9441
z'	−0 2 54.0621	+0 3 16.7349
λ'	− 9.0440	−10.8826
$z' - \lambda'$	−0 3 3.106	+0 3 5.852
z	−0 3 15.5323	+0 2 52.8467
λ	+ 9.9787	+ 9.9787
$z + \lambda$	−0 3 5.554	+0 3 2.825
(1) + (3) = $\log\sin\frac{1}{2}\theta$	6.5898488n	6.5898337
	° ′ ″	° ′ ″
$\frac{1}{2}\theta$	−0 1 20.2183	+0 1 20.2156
θ	−0 2 40.437	+0 2 40.431

TABULAR VALUES OF THE CONSTANTS ϵ_1, ψ, AND λ, FOR THE EPOCHS $1800 \pm t$.

Epoch.	ϵ_1	Δ_1	Δ_1	ψ	Δ_1	Δ_2	λ	Δ_2	Δ_2
	° ′ ″	″	″	° ′ ″	′ ″	″	″	″	″
1755	+23 27 54.234884			−0 37 47.3105			− 7.2931		
		−.004822			+6 43.1095			+1.3682	
1763	+23 27 54.230062		+.000941	−0 31 4.2010		−.0139	− 5.9249		−.0310
		−.003881			+6 43.0956			+1.3372	
1771	+23 27 54.226181		+.000941	−0 24 21.1054		−.0138	− 4.5877		−.0309
		−.002940			+6 43.0818			+1.3063	
1779	+23 27 54.223241		+.000941	−0 17 38.0236		−.0139	− 3.2814		−.0311
		−.001999			+6 43.0679			+1.2752	
1787	+23 27 54.221242		+.000941	−0 10 54.9557		−.0139	− 2.0062		−.0309
		−.001058			+6 43.0540			+1.2443	
1795	+23 27 54.220184		+.000940	−0 4 11.9017		−.0139	− 0.7619		−.0309
		−.000118			+6 43.0401			+1.2134	
1803	+23 27 54.220066		+.000941	+0 2 31.1384		−.0138	+ 0.4515		−.0310
		+.000823			+6 43.0263			+1.1824	
1811	+23 27 54.220889		+.000941	+0 9 14.1647		−.0139	+ 1.6339		−.0309
		+.001764			+6 43.0124			+1.1515	
1819	+23 27 54.222653		+.000941	+0 15 57.1771		−.0139	+ 2.7854		−.0310
		+.002705			+6 42.9985			+1.1205	
1827	+23 27 54 225358		+.000941	+0 22 40.1756		−.0139	+ 3.9059		−.0310
		+.003646			+6 42.9846			+1.0895	
1835	+23 27 54.229004		+.000940	+0 29 23.1602		−.0139	+ 4.9954		−.0309
		+.004586			+6 42.9707			+1.0586	
1843	+23 27 54.233590		+.000941	+0 36 6.1309		−.0138	+ 6.0540		−.0310
		+.005527			+6 42.9569			+1.0276	
1851	+23 27 54.239117		+.000941	+0 42 49.0878		−.0138	+ 7.0816		−.0309
		+.006468			+6 42.9431			+0.9967	
1859	+23 27 54.245585		+.000941	+0 49 32.0309		−.0140	+ 8.0783		−.0310
		+.007409			+6 42.9291			+0.9657	
1867	+23 27 54.252994		+.000941	+0 56 14.9600		−.0138	+ 9.0440		−.0310
		+.008350			+6 42.9153			+0.9347	
1875	+23 27 54.261344		+.000940	+1 2 57.8753		−.0140	+ 9.9787		−.0309
		+.009290			+6 42.9013			+0.9038	
1883	+23 27 54 270634		+.000941	+1 9 40.7766		−.0138	+10.8825		−.0310
		+.010231			+6 42.8875			+0.8728	
1891	+23 27 54.280865		+.000941	+1 16 23.6641		−.0138	+11.7553		−.0309
		+.011172			+6 42.8737			+0.8419	
1899	+23 27 54.292037		+.000941	+1 23 6.5378		−.0140	+12.5972		−.0310
		+.012113			+6 42.8597			+0.8109	
1907	+23 27 54.304150		+.000941	+1 29 49.3975		−.0138	+13.4081		−.0310
		+.013054			+6 42,8459			+0.7799	
1915	+23 27 54.317204		+.000940	+1 36 32 2434		−.0139	+14.1880		−.0309
		+.013994			+6 42.8320			+0.7490	
1923	+23 27 54.331198		+.000941	+1 43 15.0754		−.0139	+14.9370		−.0310
		+.014935			+6 42.8181			+0.7180	
1931	+23 27 54.346133		+.000941	+1 49 57.8935		−.0138	+15.6550		−.0309
		+.015876			+6 42.8043			+0.6871	
1939	+23 27 54.362009		+.000941	+1 56 40.6978		−.0138	+16.3421		−.0310
		+.016817			+6 42.7904			+0.6561	
1947	+23 27 54.378826		+.000941	+2 3 23.4882		−.0139	+16.9982		−.0309
		+.017758			+6 42.7765			+0.6252	
1955	+23 27 54.396584			+2 10 6.2647			+17.6234		

TABULAR VALUES OF THE CONSTANTS $z' - \lambda'$, $z + \lambda$, AND θ, FOR THE EPOCHS $1800 \pm t$.

Epoch.	$z' - \lambda'$	Δ_1	Δ_2	$z + \lambda$	Δ_1	Δ_2	θ	Δ_1	Δ_2
	° ′ ″	′ ″	″	° ′ ″	′ ″	″	° ′ ″	′ ″	″
1755	0 46 3.1047			−0 46 4.9535			−0 40 7.0594		
		+3 4.1291			+3 4.2880			+2 40.5008	
1763	−0 42 58.9756		+.0241	−0 43 0.6655		−.0072	−0 37 26.5586		−.0042
		+3 4.1532			+3 4.2808			+2 40.4966	
1771	−0 39 54.8224		+.0237	−0 39 56.3847		−.0069	−0 34 46.0620		−.0036
		+3 4.1769			+3 4.2739			+2 40.4930	
1779	−0 36 50.6455		+.0241	−0 36 52.1108		−.0071	−0 32 5 5690		−.0044
		+3 4.2010			+3 4 2668			+2 40.4886	
1787	−0 33 46.4445		+.0238	−0 33 47.8440		−.0072	−0 29 25.0804		−.0036
		+3 4.2248			+3 4.2596			+2 40.4850	
1795	−0 30 42.2197		+.0244	−0 30 43.5844		−.0071	−0 26 44.5954		−.0038
		+3 4.2492			+3 4 2525			+2 40.4812	
1803	−0 27 37.9705		+.0238	−0 27 39.3319		−.0069	−0 24 4.1142		−.0047
		+3 4.2730			+3 4.2456			+2 40.4765	
1811	0 24 33.6975		+.0240	−0 24 35.0863		−.0067	−0 21 23.6377		−.0050
		+3 4.2970			+3 4.2389			+2 40.4715	
1819	−0 21 29.4005		+.0241	−0 21 30.8474		−.0068	−0 18 43.1662		−.0045
		+3 4.3211			+3 4.2321			+2 40.4670	
1827	−0 18 25.0794		+.0245	−0 18 26.6153		−.0066	−0 16 2.6992		−.0042
		+3 4.3456			+3 4.2255			+2 40.4628	
1835	−0 15 20.7338		+.0247	−0 15 22.3898		−.0065	−0 13 22.2364		−.0052
		+3 4.3703			+3 4.2190			+2 40 4576	
1843	0 12 16.3635		+.0246	−0 12 18.1708		−.0064	−0 10 41.7788		−.0052
		+3 4.3949			+3 4.2126			+2 40.4524	
1851	−0 9 11.9686		+.0243	−0 9 13.9582		−.0070	−0 8 1.3264		−.0050
		+3 4.4192			+3 4.2056			+2 40.4474	
1859	−0 6 7.5494		+.0241	−0 6 9.7526		−.0066	−0 5 20.8790		−.0058
		+3 4.4433			+3 4.1990			+2 40.4416	
1867	−0 3 3.1061			−0 3 5.5536			−0 2 40.4374		
1875	. . . . .	. . .	. . .	. . . . .	. . .	. . .	. . . . .	. . . .	. . .
1883	+0 3 5.8523			+0 3 2.8254			+0 2 40.4312		
		+3 4 5154			+3 4.1845			+2 40.4262	
1891	+0 6 10 3677		+.0277	+0 6 7.0099		−.0137	+0 5 20.8574		−.0067
		+3 4.5431			+3 4.1708			+2 40.4195	
1899	+0 9 14.9108		+.0244	+0 9 11.1807		−.0048	+0 8 1.2769		−.0058
		+3 4.5675			+3 4.1660			+2 40.4137	
1907	+0 12 19.4783		+.0247	+0 12 15.3467		−.0050	+0 10 41.6906		−.0059
		+3 4.5922			+3 4.1610			+2 40.4078	
1915	+0 15 24.0705		+.0242	+0 15 19 5077		−.0053	+0 13 22.0984		−.0059
		+3 4.6164			+3 4.1557			+2 40 4019	
1923	+0 18 28.6869		+.0248	+0 18 23.6634		−.0061	+0 16 2.5003		−.0060
		+3 4.6412			+3 4.1496			+2 40.3959	
1931	+0 21 33.3281		+.0249	+0 21 27.8130		−.0061	+0 18 42.8962		−.0067
		+3 4.6661			+3 4.1435			+2 40.3892	
1939	+0 24 37.9942		+.0252	+0 24 31.9565		−.0063	+0 21 23.2854		−.0066
		+3 4 6913			+3 4.1372			+2 40.3826	
1947	+0 27 42.6855		+.0251	+0 27 36.0937		−.0065	+0 24 3.6680		−.0068
		+3 4.7164			+3 4.1307			+2 40.3758	
1955	+0 30 47.4019			+0 30 40.2244			+0 26 44.0438		

The following example is given in illustration of the application of equations (6), the problem being to reduce from the mean equator and equinox of 1875.0 to the mean equator and equinox of 1867.0 and of 1883.0. Given the co-ordinates of Groombridge 1119 for 1875.0, to find the values for 1867.0 and 1883.0.

α for 1875.0 = 7h 29m 5.631s δ for 1875.0 = +88° 59′ 37.69″

	For 1867.0.	For 1883.0.
	° ′ ″	° ′ ″
α 1875.0	112 16 24.465	112 16 24.465
$z + \lambda$	−0 3 5.554	+0 3 2.825
A	112 13 18.911	112 19 27.290
log tan δ	1.7553949	1.7553949
log cos A	9.5777158n	9.5796095n
log tan M	2.1776791n	2.1757854n
	° ′ ″	° ′ ″
M	+90 22 50.060	+90 22 56.048
θ	− 0 2 40.437	+ 0 2 40.431
$M + \theta$	+90 20 9.623	+90 25 36.479
log tan A	0.3887667n	0.3865553n
log cos M	7.8223112n	7.8242051n
log tan A cos M	8.2110779	8.2107604
log cos $(M + \theta)$	7.7682224n	7.8720975n
log tan A'	0.4428555n	0.3386629n
	° ′ ″	° ′ ″
A'	+109 50 3.500	+114 37 52.839
$z' - \lambda'$	− 0 3 3.166	+ 0 3 5.852
	° ′ ″	° ′ ″
α' in arc	+109 47 0.394	+114 40 58.691
	h m. s.	h. m. s.
α' in time	7 19 8.026	7 38 43.913
log tan $(M + \theta)$	2.2317701n	2.1278903n
log cos A'	9.5305854n	9.6199049n
log tan δ'	1.7623555	1.7477952
	° ′ ″	° ′ ″
δ'	+89 0 35.27	+88 58 33.76

In like manner, the following values of α and δ were computed for intervals of eight years.

Date.	α	δ	Date.	α	δ
	h. m. s.	° ′ ″		h. m. s.	° ′ ″
1755	4 45 55.203	+89 1 1.38	1859	7 8 52.315	+89 1 26.19
1763	4 56 19.577	+89 1 48.90	1867	7 19 8.026	+88 0 35.27
1771	5 6 59.542	+89 2 29.33	1875	7 29 5.631	+88 59 37.69
1779	5 17 52.998	+89 3 2.41	1883	7 38 43.913	+88 58 33.76
1787	5 28 57.519	+89 3 27.93	1891	7 48 1.994	+88 57 23.81
1795	5 40 10.397	+89 3 45.70	1899	7 56 59.309	+88 56 8.17
1803	5 51 28.695	+89 3 55.62	1907	8 5 35.579	+88 54 47.17
1811	6 2 49.333	+89 3 57.66	1915	8 13 50.774	+88 53 21.14
1819	6 14 9.166	+89 3 51.70	1923	8 21 45.073	+88 51 50.40
1827	6 25 25.071	+89 3 37.84	1931	8 29 18.828	+88 50 15.24
1835	6 36 34.034	+89 3 16.18	1939	8 36 32.527	+88 48 35.97
1843	6 47 33.225	+89 2 46.91	1947	8 43 26.768	+88 46 52.87
1851	6 58 20.073	+89 2 10.16	1955	8 50 2.231	+88 45 6.21

The places for single years will be easily obtained by successive interpolations to the middle, by means of the formula (see Chauvenet, Vol. I. p. 88),

$$F^{\frac{1}{2}} = \tfrac{1}{2}(F + F') - \tfrac{1}{8}\left[b_0 - \tfrac{3}{16}\left[d_0 - \tfrac{5}{24}(f_0 - \text{\&c.})\right]\right] \qquad (9)$$

Bessel has given a method (see Wolfers, Tab. Reg., pp. lii, liii) by which the true values of α' and δ' may be computed from an approximate value of α'.

Let

$$\alpha_1' = \text{an approximate value of } \alpha',$$

$$A_1' = \alpha_1' - (z' - \lambda').$$

From Napier's first and second Analogies,

$$\tan \tfrac{1}{2}(\delta' - \delta) = \frac{\cos \frac{1}{2}(A_1' + A)}{\cos \frac{1}{2}(A_1' - A)} \tan \tfrac{1}{2}\theta \qquad (10)$$

$$\operatorname{cotan} \tfrac{1}{2}(\delta' - \delta) = \frac{\sin \frac{1}{2}(A_1' + A)}{\sin \frac{1}{2}(A_1' - A)} \tan \tfrac{1}{2}\theta \qquad (11)$$

Let the variations in the logarithms of the given functions for a change of 1″ have the following designations:

$\varDelta \log \cos \frac{1}{2}(A_1' + A) = c$ $\qquad\qquad$ $\varDelta \log \sin \frac{1}{2}(A_1' - A) = s'$

$\varDelta \log \cos \frac{1}{2}(A_1' - A) = c'$ $\qquad\qquad$ $\varDelta \log \tan \frac{1}{2}(\delta' - \delta) = t$

$\varDelta \log \sin \frac{1}{2}(A_1' + A) = s$ $\qquad\qquad$ $\varDelta \log \tan \frac{1}{2}(\delta' + \delta) = t'$

d = the value of $\frac{1}{2}(\delta' - \delta)$ obtained from equation (10)

d' = " " $\frac{1}{2}(\delta' + \delta)$ " " " (11)

x = the required correction to α_1' in order to obtain α'

$$\beta = \frac{\frac{1}{2}(c - c')}{t} \qquad\qquad \gamma = \frac{\frac{1}{2}(\delta - \delta')}{t'}$$

Then

$$x = \frac{\delta - (d' - d)}{\gamma - \beta}$$

$$\alpha' = \alpha_1' + x. \tag{12}$$

$$\delta' = d' + d + (\beta + \gamma)\, x. \tag{13}$$

This method may be conveniently applied when we have a series of values of α and require any following term of the series. From the differences of the given values of α an approximation to the true value may be obtained, from which the correction x can be computed. The exact values of α' and δ' will then be determined from equations (12) and (13) respectively.

Let us assume that the values of α have been found for 1875, 1883, and 1891 as follows:

	h. m. s.	Δ_1 m. s.	Δ_2 s.	
1875	7 29 5.631			$\delta = +88°\ 59'\ 37''.69$
		+9 38.282		
1883	7 38 43.913		−20.201	
		+9 18.081		
1891	7 48 1.994			

Assuming the second difference, $-20^s.201$, as a constant, we obtain, for 1899,

$$\alpha_1' = 7^h\ 56^m\ 59^s.874$$

To find the true α' for 1899, we have

	h. m. s.
α_1'	7 56 59.874
	° ′ ″
α_1' in arc	+119 14 58.110
$z' - \lambda'$	+ 0 9 14.911
A_1'	+119 5 43.199
α	+112 16 24.465
$z + \lambda$	+ 0 9 11.181
A	+112 25 35.646
$\frac{1}{2}(A_1' + A)$	+115 45 39.422
$\frac{1}{2}(A_1' - A)$	+ 3 20 3.776
$\frac{1}{2}\theta$	+ 0 4 0.6385

$\log \cos \frac{1}{2}(A_1' + A)$	9.6381071n
$\log \cos \frac{1}{2}(A_1' - A)$	9.9992641
$\log \dfrac{\cos \frac{1}{2}(A_1' + A)}{\cos \frac{1}{2}(A_1' - A)}$	9.6388430n
$\log \tan \frac{1}{2}\theta$	7.0669400
$\log \tan \frac{1}{2}(\delta' - \delta)$	6.7057830n
$\log \sin \frac{1}{2}(A_1' + A)$	9.9545393
$\log \sin \frac{1}{2}(A_1' - A)$	8.7646475
$\log \dfrac{\sin \frac{1}{2}(A_1' + A)}{\sin \frac{1}{2}(A_1' - A)}$	1.1898918
$\log \tan \frac{1}{2}\theta$	7.0669400
$\log \text{cotan} \frac{1}{2}(\delta' + \delta)$	8.2568318

			° ′ ″
$c = +43.6$	$s = -\ 10.2$	$t\ -41660$	$d\ -\ 0\ 1\ 44.763$
$c' = -\ 1.2$	$s' = +361.3$	$t'\ -\ 1166.1$	$d'\ +88\ 57\ 54.285$

$$\beta = \tfrac{1}{2}\left(\frac{+43.6 + 1.2}{-41660}\right) = -0.00054 \qquad \gamma = \tfrac{1}{2}\left(\frac{-10.2 - 361.3}{1166.1}\right) = +0.15930$$

$$\gamma - \beta = +0.15984 \qquad \beta + \gamma = +0.15876$$

$$x = \frac{88^\circ\ 59'\ 37''.69 - 88^\circ\ 59'\ 39''.048}{+0.15984} = -8''.496$$

	h. m. s
$\alpha_1' =$	7 56 59.874
$x =$	−0.566
$\alpha' =$	7 56 59.308

$\log(\beta + \gamma)$	9.2007411
$\log x$	0.9292145n
$\log(\beta + \gamma)\, x$	0.1299556n
	° ′ ″
$(\beta + \gamma)\, x$	−1.349
$d' + d$	88 56 9.522
δ'	88 56 8.17

Development of the Functions α and δ by Means of Differential Coefficients, expressed in Terms of the Ascending Powers of the Time.

Given α_0 and δ_0 for any time t_0, to obtain α and δ for any time t', we have, by Taylor's Theorem,

$$\alpha = \alpha_0 + \frac{d\alpha}{dt}(t' - t_0) + \frac{1}{2}\frac{d^2\alpha}{dt^2}(t' - t_0)^2 + \frac{1}{2.3}\frac{d^3\alpha}{dt^3}(t' - t_0)^3 + \frac{1}{2.3.4}\frac{d^4\alpha}{dt^4}(t' - t_0)^4 +, \&c. \qquad (14)$$

$$\delta = \delta_0 + \frac{d\delta}{dt}(t' - t_0) + \frac{1}{2}\frac{d^2\delta}{dt^2}(t' - t_0)^2 + \frac{1}{2.3}\frac{d^3\delta}{dt^3}(t' - t_0)^3 + \frac{1}{2.3.4}\frac{d^4\delta}{dt^4}(t' - t_0)^4 +, \&c. \qquad (15)$$

We must now find expressions convenient for the numerical computation of the differential coefficients $\frac{d\alpha}{dt}, \frac{d^2\alpha}{dt^2}, \frac{d^3\alpha}{dt^3}, \frac{d^4\alpha}{dt^4}$, &c.

The form of development given by Bessel is at once the earliest and the most complete published, since it is carried to the fourth power of the time: it is also quite as well adapted for logarithmic computation as the more modern forms.

Introducing into the denominators that power of the radius which will render all the terms homogeneous, we have (see Tab. Reg., pp. x, xi, and Fundamenta Astronomiæ, p. 301), after multiplying by the coefficients in the development by Taylor's Theorem,

$$\frac{d\alpha}{dt} = m + n \tan\delta \sin\alpha. \tag{16}$$

$$\frac{d^2\alpha}{dt^2} = m' + \frac{n^2}{R}\tan^2\delta \sin 2\alpha + \frac{nm}{R}\tan\delta\cos\alpha + \frac{n^2}{2R}\sin 2\alpha + n'\tan\delta\sin\alpha. \tag{17}$$

$$\begin{aligned}\frac{d^3\alpha}{dt^3} = {} & \frac{n^2 m}{2R^2} + \frac{2n^3}{R^2}\tan^3\delta\sin 3\alpha + \frac{3n^2 m}{R^2}\tan^2\delta\cos 2\alpha + \frac{3n^3}{2R^2}\tan\delta\sin 3\alpha + \left(\frac{n^3}{2R^2} - \frac{nm^2}{R^2}\right)\tan\delta\sin\alpha \\ & + \frac{3n^2 m}{2R^2}\cos 2\alpha + \frac{m'n + 2n'm}{R}\tan\delta\cos\alpha + \frac{3n'n}{R}\tan^2\delta\sin 2\alpha + \frac{3n'n}{2R}\sin 2\alpha.\end{aligned} \tag{18}$$

$$\begin{aligned}\frac{d^4\alpha}{dt^4} = {} & \frac{6n^4}{R^3}\tan^4\delta\sin 4\alpha + \frac{{}^{*}12n^3 m}{R^3}\tan^3\delta\cos 3\alpha + \frac{6n^4}{R^3}\tan^2\delta\sin 4\alpha + \left(\frac{2n^4}{R^3} - \frac{7n^2m^2}{R^3}\right)\tan^2\delta\sin 2\alpha \\ & + \frac{9n^3 m}{R^3}\tan\delta\cos 3\alpha + \left(\frac{2n^3 m}{R^3} - \frac{nm^3}{R^3}\right)\tan\delta\cos\alpha + \frac{3n^4}{4R^3}\sin 4\alpha + \left(\frac{n^4}{R^3} - \frac{7n^2m^2}{2R^3}\right)\sin 2\alpha,\end{aligned} \tag{19}$$

&c., &c., &c.

$$\frac{d\delta}{dt} = n\cos\alpha. \tag{20}$$

$$\frac{d^2\delta}{dt^2} = -\frac{n^2}{R}\tan\delta\sin^2\alpha - \frac{nm}{R}\sin\alpha + n'\cos\alpha. \tag{21}$$

$$\begin{aligned}\frac{d^3\delta}{dt^3} = {} & -\frac{3n^3}{R^2}\tan^2\delta\sin^2\alpha\cos\alpha - \frac{3n^2 m}{R^2}\tan\delta\sin\alpha\cos\alpha - \left[\frac{n(m^2+n^2)}{R^2}\cos\alpha - \frac{n^3}{R^2}\cos^3\alpha\right] \\ & - \left(\frac{m'n + 2n'm}{R}\right)\sin\alpha - \frac{2n'n}{R}\tan\delta\sin^2\alpha.\end{aligned} \tag{22}$$

---

[*] Engelmann (see Abhandlungen von Bessel, Vol. I. p. 277) gives $\frac{8n^3 m}{R^3}$ for this term.

$$\begin{aligned}\frac{d^4\delta}{dt^4} &= \frac{3n^4}{R^3}\tan^3\delta\,[\sin^4\alpha - 4\sin^2\alpha\cos^2\alpha] + \frac{6n^3m}{R^3}\tan^2\delta\sin\alpha + \frac{18n^3m}{R^3}\tan^2\delta\sin\alpha\cos^2\alpha \\ &+ \frac{7n^2m^2}{R^3}\tan\delta\sin^2\alpha - \frac{3n^2m^2}{R^3}\tan\delta + \frac{n^4}{R^3}\tan\delta\,(\sin^4\alpha - 8\sin^2\alpha\cos^2\alpha) \qquad (23) \\ &+ \left[\frac{nm(m^2+n^2)}{R^3}\sin\alpha - \frac{6n^3m}{R^3}\sin\alpha\cos^2\alpha\right] \\ &\qquad\qquad \text{\&c.,} \qquad \text{\&c.,} \qquad \text{\&c.}\end{aligned}$$

For the computation of the numerical coefficients, we have the following constants for 1875.0. (See Pub. XIV., p. 51.)

For the reduction in Right Ascension,

$$\begin{array}{llll} m = \overset{s.}{3}.072245 & n = \overset{s.}{1}.336949 & m' = +\overset{s.}{0}.0000189933 & \\ \log m = 0.4874558 & \log n = 0.1261147 & \log m' = 5.2786011 & \log R = \overset{s.}{4}.1383338 \\ \log m^2 = 0.9749116 & \log n^2 = 0.2522294 & & \log R^2 = 8.2766676 \\ \log m^3 = 1.4623674 & \log n^3 = 0.3783441 & n' = -0.00000575333 & \log R^3 = 12.4150014 \\ & \log n^4 = 0.5044588 & \log n' = 4.7599145n & \end{array}$$

For the reduction in Declination,

$$\begin{array}{llll} m = \overset{''}{46}.08367 & n = \overset{''}{20}.05423 & m' = +\overset{''}{0}.0002849 & \\ \log m = 1.6635471 & \log n = 1.3022060 & \log m' = 6.4546924 & \log R = \overset{''}{5}.3144251 \\ \log m^2 = 3.3270942 & \log n^2 = 2.6044120 & & \log R^2 = 10.6288502 \\ & \log n^3 = 3.9066180 & n' = -0.0000863 & \log R^3 = 15.9432753 \\ & \log n^4 = 5.2088240 & \log n' = 5.9360108n & \end{array}$$

Substituting in the preceding equations, we have:

$$\frac{d\alpha}{dt} = +\overset{s.}{3}.072245 + [0.1261147]\tan\delta\sin\alpha. \qquad (24)$$

$$\begin{aligned}\frac{d^2\alpha}{dt^2} &= +\overset{s.}{0}.00001899 + [6.1138956]\tan^2\delta\sin 2\alpha + [6.4752367]\tan\delta\cos\alpha + [5.8128656]\sin 2\alpha \\ &\qquad + [4.7599145n]\tan\delta\sin\alpha. \qquad (25)\end{aligned}$$

$$\begin{aligned}\frac{d^3\alpha}{dt^3} &= +\overset{s.}{0}.0000000145 + [2.4027065]\tan^3\delta\sin 3\alpha + [2.9401389]\tan^2\delta\cos 2\alpha + [2.2777678]\tan\delta\sin 3\alpha \\ &\qquad + [2.7811577n]\tan\delta\sin\alpha + [2.6391089]\cos 2\alpha + [0.8598285n]\tan\delta\cos\alpha \qquad (26) \\ &\qquad + [1.2248167n]\tan^2\delta\sin 2\alpha + [0.9237867]\sin 2\alpha.\end{aligned}$$

$$\frac{d^4\alpha}{dt^4} = {}^{*}+ [\bar{8}.8676086] \tan^4\delta \sin 4\alpha + [\bar{9}.5299797] \tan^3\delta \cos 3\alpha + [\bar{8}.8676086] \tan^2\delta \sin 4\alpha$$
$$+ [\bar{9}.6330799n] \tan^2\delta \sin 2\alpha + [\bar{9}.4050410] \tan\delta \cos 3\alpha + [\bar{8}.9667591n] \tan\delta \cos\alpha \qquad (27)$$
$$+ [\bar{7}.9645186] \sin 4\alpha + [\bar{9}.3320498n] \sin 2\alpha.$$

$$\frac{d\delta}{dt} = + [1.3022060] \cos\alpha. \qquad (28)$$

$$\frac{d^2\delta}{dt^2} = + [7.2899869n] \tan\delta \sin^2\alpha + [7.6513280n] \sin\alpha + [5.9360108n] \cos\alpha. \qquad (29)$$

$$\frac{d^3\delta}{dt^3} = + [3.7548891n] \tan^2\delta \sin^2\alpha \cos\alpha + [4.1162302n] \tan\delta \sin\alpha \cos\alpha + [4.0757367n] \cos\alpha$$
$$+ [3.2777678] \cos^3\alpha + [2.0359378] \sin\alpha + [2.4009130] \sin^2\alpha \tan\delta. \qquad (30)$$

$$\frac{d^4\delta}{dt^4} = + [\bar{9}.7426700] \tan^3\delta \sin^4\alpha + [0.3447299n] \tan^3\delta \sin^2\alpha \cos^2\alpha + [0.4050411] \tan^2\delta \sin\alpha$$
$$+ [0.8821623] \tan^2\delta \sin\alpha \cos^2\alpha + [0.8333289] \tan\delta \sin^2\alpha + [0.4653522n] \tan\delta \qquad (31)$$
$$+ [\bar{9}.2655487] \tan\delta \sin^4\alpha + [0.1686387n] \tan\delta \sin^2\alpha \cos^2\alpha + [0.4248824] \sin\alpha$$
$$+ [0.4050411n] \sin\alpha \cos^2\alpha.$$

Hill has given a slightly different form of development for $\frac{d^3\alpha}{dt^3}$ and $\frac{d^3\delta}{dt^3}$. (See Star Tables of the American Ephemeris, p. xvii.)

Introducing the required power of the radius, we have:

$$\frac{d^2\alpha}{dt^2} = m' + \frac{n^2}{2R} \sin 2\alpha + n' \sin\alpha \tan\delta + \frac{mn}{R} \cos\alpha \tan\delta + \frac{n^2}{R} \sin 2\alpha \tan^2\delta. \qquad (32)$$

$$\frac{d^3\alpha}{dt^3} = \frac{mn^2}{2R^2} + \frac{3mn^2}{2R^2} \cos 2\alpha + \frac{3nn'}{2R} \sin 2\alpha + \frac{2n^3 - m^2 n}{R^2} \sin\alpha \tan\delta + \frac{3n^3}{R^2} \sin\alpha \cos 2\alpha \tan\delta$$
$$+ \frac{2mn' + nm'}{R} \cos\alpha \tan\delta + \frac{3mn^2}{R^2} \cos 2\alpha \tan^2\delta + \frac{3nn'}{R} \sin 2\alpha \tan^2\delta \qquad (33)$$
$$+ \frac{2n^3}{R^2} \sin\alpha \tan^3\delta + \frac{4n^3}{R^2} \cos 2\alpha \tan^3\delta.$$

$$\frac{d^2\delta}{dt^2} = - \frac{mn}{R} \sin\alpha + n' \cos\alpha - \frac{n^2}{R} \sin^2\alpha \tan\delta. \qquad (34)$$

---

[*] One dash over the characteristic of the logarithm indicates one completion of the cycle, and two dashes indicate two completions of a cycle.

$$\frac{d^3\delta}{dt^3} = -\left(\frac{2mn' + nm'}{R}\right)\sin\alpha - \frac{m^2 n}{R^2}\cos\alpha - \frac{n^3}{R^2}\sin^2\alpha\cos\alpha - \frac{3mn^2}{2R^2}\sin 2\alpha\tan\delta$$
$$- \frac{3nn'}{R}\sin^2\alpha\tan\delta - \frac{3n^3}{R^2}\sin^2\alpha\cos\alpha\tan^2\delta. \qquad (35)$$

Substituting the preceding numerical values of the constants for 1875.0, and adopting the convenient form which Hill has given on p. xix for $\frac{d^2\alpha}{dt^2}$ and $\frac{d^2\delta}{dt^2}$, the formulæ become:

$$\frac{d^2\alpha}{dt^2} = + \overset{s.}{0}.00003221 + [4.6338048n]\frac{d\alpha}{dt} + [5.9877809]\frac{d\alpha}{dt}\cos\alpha\tan\delta$$
$$+ [4.8116896n]\frac{d\delta}{dt}\sin\alpha\sec^2\delta. \qquad (36)$$

$$\frac{d^3\alpha}{dt^3} = + \overset{s.}{0}.0000000145 + [2.6391089]\cos 2\alpha + [0.9237867n]\sin 2\alpha + [2.6176279n]\sin\alpha\tan\delta$$
$$+ [2.5787978]\sin\alpha\cos 2\alpha\tan\delta + [0.8598285n]\cos\alpha\tan\delta + [2.9401389]\cos 2\alpha\tan^2\delta \qquad (37)$$
$$+ [1.2248167n]\sin 2\alpha\tan^2\delta + [2.4027665]\sin\alpha\tan^3\delta + [2.7037365]\sin\alpha\cos 2\alpha\tan^3\delta.$$

$$\frac{d^2\delta}{dt^2} = + [4.6338048n]\frac{d\delta}{dt} + [7.1638722n]\frac{d\alpha}{dt}\sin\alpha. \qquad (38)$$

$$\frac{d^3\delta}{dt^3} = + [2.0359378]\sin\alpha + [4.0004500n]\cos\alpha + [3.2777678n]\sin^2\alpha\cos\alpha \qquad (39)$$
$$+ [3.8152002n]\sin 2\alpha\tan\delta + [2.4009130]\sin^2\alpha\tan\delta + [3.7548891n]\sin^2\alpha\cos\alpha\tan^2\delta.$$

Menten has introduced a convenient modification of the expressions for $\frac{d^2\alpha}{dt^2}$ and $\frac{d^2\delta}{dt^2}$. (See Astronomische Beobachtungen auf der Sternwarte zu Bonn, VII. pp. 147–148.)

Let

$$A = m' + \frac{n^2}{2R}\sin 2\alpha. \qquad A' = n'\cos\alpha - \frac{mn}{R}\sin\alpha.$$
$$\log B = \log\left[\frac{mn}{R}\cos\alpha + n'\sin\alpha\right]. \qquad \log B' = \log\left(-\frac{n^2}{R}\sin^2\alpha\right). \qquad (40)$$
$$\log C = \log\frac{n^2}{R}\sin 2\alpha.$$

In which A, B, and C are expressed in seconds of time, and A' and B' in seconds of arc. Or,

$$
\begin{aligned}
A &= + \overset{s.}{0.00001899} + [5.8128656] \sin 2\alpha. \\
\log B &= + [4.7599145n] \sin \alpha + [6.4752367] \cos \alpha. \\
\log C &= + [6.1138956] \sin 2\alpha. \\
A' &= + [7.6513280n] \sin \alpha + [5.9360108n] \cos \alpha. \\
\log B &= + [7.2899869n] \sin^2 \alpha.
\end{aligned}
\tag{41}
$$

Then,

$$
\begin{aligned}
\frac{d^2 \alpha}{d t^2} &= A + B \tan \delta + C \tan^2 \delta. \\
\frac{d^2 \delta}{d t^2} &= A' + B' \tan \delta.
\end{aligned}
\tag{42}
$$

In like manner Tiele has simplified the computation of $\frac{d^3 \alpha}{d t^3}$ and $\frac{d^3 \delta}{d t^3}$. (See Astronomische Beobachtungen auf der Sternwarte zu Bonn, VII. p. 149.)

He gives the equations:

$$
\begin{aligned}
\frac{d^3 \alpha}{d t^3} = & \left[-m n^2 + 3 n n' \sin \alpha \cos \alpha + 3 m n^2 \cos^2 \alpha\right] \\
& + \left[(m' n + 2 m n') \cos \alpha - n (m^2 + n^2) \sin \alpha + 6 n^3 \sin \alpha \cos^2 \alpha\right] \tan \delta \\
& + \left[-3 m n^2 + 6 n n' \sin \alpha \cos \alpha + 6 m n^2 \cos^2 \alpha\right] \tan^2 \delta \\
& + \left[-2 n^3 \sin \alpha + 8 n^3 \sin \alpha \cos^2 \alpha\right] \tan^3 \delta.
\end{aligned}
\tag{43}
$$

$$
\begin{aligned}
\frac{d^3 \delta}{d t^3} = & \left[-(m' n + 2 m n') \sin \alpha - m^2 n \cos \alpha - n^3 \cos \alpha \sin^2 \alpha\right] \\
& + \left[-3 n n' \sin^2 \alpha - 3 m n^2 \sin \alpha \cos \alpha\right] \tan \delta \\
& - 3 n^3 \sin^2 \alpha \cos \alpha \tan^2 \delta.
\end{aligned}
\tag{44}
$$

Assuming

$$
\begin{aligned}
P &= -\frac{m n^2}{R^2} + \frac{3 n n'}{R} \sin \alpha \cos \alpha + \frac{3 m n^2}{R^2} \cos^2 \alpha. \\
P_1 &= + \left(\frac{m' n + 2 m n'}{R}\right) \cos \alpha - \frac{(m n^2 + n^2)}{R^2} \sin \alpha + \frac{6 n^3}{R^2} \sin \alpha \cos^2 \alpha. \\
P_2 &= -\frac{3 m n^2}{R^2} + \frac{6 n n'}{R} \sin \alpha \cos \alpha + \frac{6 m n^2}{R^2} \cos^2 \alpha. \\
P_3 &= -\frac{2 n^3}{R^2} \sin \alpha + \frac{8 n^3}{R^2} \sin \alpha \cos^2 \alpha. \\
Q &= -\left(\frac{m' n + 2 m n'}{R}\right) \sin \alpha - \frac{m^2 n}{R^2} \cos \alpha - \frac{n^3}{R^2} \cos \alpha \sin^2 \alpha. \\
Q_1 &= -\frac{3 n n'}{R} \sin^2 \alpha - \frac{3 m n^2}{R^2} \sin \alpha \cos \alpha. \\
Q_2 &= -\frac{3 n^3}{R^2} \cos \alpha \sin^2 \alpha.
\end{aligned}
\tag{45}
$$

Then,

$$\begin{aligned}\frac{d^3\alpha}{dt^3} &= P + P_1\tan\delta + P_2\tan^2\delta + P_3\tan^3\delta.\\ \frac{d^3\delta}{dt^3} &= Q + Q_1\tan\delta + Q_2\tan^2\delta.\end{aligned}\tag{46}$$

Introducing the constants for 1875.0 we have:

$$\begin{aligned}P &= -\overset{s.}{0}.0000000290 + [1.2248167n]\sin\alpha\cos\alpha + [2.9401389]\cos^2\alpha.\\ P_1 &= +[0.0816772n]\cos\alpha + [2.8996767n]\sin\alpha + [2.8798278]\cos^2\alpha\sin\alpha.\\ P_2 &= -\overset{s.}{0}.0000000871 + [1.5258467n]\sin\alpha\cos\alpha + [3.2411689]\cos^2\alpha.\\ P_3 &= +[3.0047665]\cos^2\alpha\sin\alpha + [2.4027065n]\sin\alpha.\\ Q &= +[2.0359378]\sin\alpha + [4.0004500n]\cos\alpha + [3.2777678n]\sin^2\alpha\cos\alpha.\\ Q_1 &= +[2.4009130]\sin^2\alpha + [4.1162302n]\sin\alpha\cos\alpha.\\ Q_2 &= +[3.7548891n]\sin^2\alpha\cos\alpha.\end{aligned}\tag{47}$$

Tabular values of A log B, log C, A' log B', P, P_1, P_2, P_3, Q, Q_1, Q_2, are given in Publication XIV. of the Astronomische Gesellschaft, but they are not carried to a sufficient number of decimal places for our purpose.

The application of the formulæ given will now be illustrated by the computation of the differential coefficients for Groombridge 1119, for the epoch 1875.0.

$$\alpha = \overset{h.}{7}\ \overset{m.}{29}\ \overset{s.}{5}.631 \qquad \delta = \overset{\circ}{88}\ \overset{\prime}{59}\ \overset{\prime\prime}{37}.69$$

$\log\sin\alpha = 9.9663226$
$\log\sin 2\alpha = 9.8460234n$
$\log\sin 3\alpha = 9.5950715n$
$\log\sin 4\alpha = 9.9999457$
$\log\sin^2\alpha = 9.9326452$
$\log\sin^4\alpha = 9.8652904$

$\log\cos\alpha = 9.5786708n$
$\log\cos 2\alpha = 9.8528923n$
$\log\cos 3\alpha = 9.9634456$
$\log\cos^2\alpha = 9.1573416$
$\log\cos^3\alpha = 8.7360124n$

$\log\tan\delta = 1.7553949$
$\log\tan^2\delta = 3.5107897$
$\log\tan^3\delta = 5.2661846$
$\log\tan^4\delta = 7.0215795$
$\log\sec^2\delta = 3.5109236$

Computation of $\frac{d\alpha}{dt}$ and $\frac{d\delta}{dt}$:

$\log n^s$	0.1261147
$\log\sin\alpha$	9.9663226
$\log\tan\delta$	1.7553949
$\log n\sin\alpha\tan\delta$	1.8478322
$n\sin\alpha\tan\delta$	+70.442079
m	3.072245
$\frac{d\alpha}{dt}$	$+\overset{s.}{73}.514324$

$\log n''$	1.3022060
$\log\cos\alpha$	9.5786708n
$\log n\cos\alpha$	0.8808768n
$\frac{d\delta}{dt}$	$-\overset{\prime\prime}{7}.6011$

Computation of $\frac{d^2\alpha}{dt^2}$:

By Bessel's Formulæ.

$\log \tan^2 \delta$	3.5107897
$\log \sin 2\alpha$	$9.8460234n$
log constant	6.1138956
log (1)	$9.4707087n$
$\log \tan \delta$	1.7553949
$\log \cos \alpha$	$9.5786708n$
log constant	6.4752367
log (2)	$7.8093024n$
$\log \sin 2\alpha$	$9.8460234n$
log constant	5.8128656
log (3)	$5.6588890n$
$\log \tan \delta$	1.7553949
$\log \sin \alpha$	9.9663226
log constant	$4.7599145n$
log (4)	$6.4816320n$

	s.
Constant	+0.00001899
(1)	− .29560297
(2)	− .00644618
(3)	− .00004559
(4)	− .00030313
$\frac{d^2\alpha}{dt^2}$	−0.30237888

By Hill's Formulæ.

$\log \frac{d\alpha}{dt}$	1.8663720
log constant	$4.6338048n$
log (1)	$6.5001768n$
$\log \frac{d\alpha}{dt}$	1.8663720
$\log \cos \alpha$	$9.5786708n$
$\log \tan \delta$	1.7553949
log constant	5.9877809
log (2)	$9.1882186n$
$\log \frac{d\delta}{dt}$	$0.8808764n$
$\log \sin \alpha$	9.9663226
$\log \sec^2 \delta$	3.5109236
log constant	4.8116896
log (3)	$9.1698122n$

	s.
Constant	+0.00003221
(1)	− .00031635
(2)	− .15424766
(3)	− .14784689
$\frac{d^2\alpha}{dt^2}$	−0.30237869

By Menten's Formulæ.

$\log \sin 2\alpha$	$9.8460234n$
log constant	5.8128656
log (1)	$5.6588890n$
constant	+.00001899
(1)	−.00004559
A	−.00002660

$\log \sin \alpha$	9.9663226
log constant	$4.7599145n$
log (1)	$4.7262371n$
$\log \cos \alpha$	$9.5786708n$
log constant	6.4752367
log (2)	$6.0539075n$

(1)	−.000053239
(2)	−.000132161
B	−.000185400
$\log B$	$6.0738649n$
$\log \tan \delta$	1.7553949
$\log B \tan \delta$	$7.8292598n$

$\log \sin 2\alpha$	$9.8460234n$
log constant	6.1138956
$\log C$	$5.9599190n$
$\log \tan^2 \delta$	3.5107897
$\log C \tan^2 \delta$	$9.4707087n$

	s.
A	−0.00002660
$B \tan \delta$	− .00674931
$C \tan^2 \delta$	− .29560297
$\frac{d^2\alpha}{dt^2}$	−0.30237888

Computation of $\frac{d^2\delta}{dt^2}$:

$\log \tan \delta$	1.7553949
$\log \sin^2 \alpha$	9.9326452
log constant	$7.2899869n$
log (1)	$8.9780270n$
$\log \sin \alpha$	9.9663226
log constant	$7.6513280n$
log (2)	$7.6176506n$
$\log \cos \alpha$	$9.5786708n$
log constant	$5.9360108n$
log (3)	5.5146816

	s.
(1)	−0.095066
(2)	− .004146
(3)	+ .000033
$\frac{d^2\delta}{dt^2}$	−0.099179

$\log \frac{d\delta}{dt}$	$0.8808764n$
log constant	$4.6338048n$
log (1)	5.5146812
$\log \frac{d\alpha}{dt}$	1.8663720
$\log \sin \alpha$	9.9663226
log constant	$7.1638722n$
log (2)	$8.9965668n$

	$''$
(1)	+0.000033
(2)	− .099212
$\frac{d^2\delta}{dt^2}$	−0.099179

$\log \sin \alpha$	9.9663226
log constant	$7.6513280n$
log (1)	$7.6176506n$
$\log \cos \alpha$	$9.5786708n$
log constant	$5.9360108n$
log (2)	5.5146816
(1)	− .004146
(2)	+ .000033
A'	− .004113

$\log \sin^2 \alpha$	9.9326452
log constant	$7.2899869n$
$\log B'$	$7.2226321n$
$\log \tan \delta$	1.7553949
$\log B' \tan \delta$	$8.9780270n$

	$''$
A'	−0.004113
$B' \tan \delta$	− .095066
$\frac{d^2\delta}{dt^2}$	−0.099179

Computation of $\frac{d^3\alpha}{dt^3}$:

By Bessel's Formulæ.

$\log \tan^3 \delta$	5.2661846
$\log \sin 3\alpha$	9.5950715*n*
log constant	2.4027065
log (1)	7.2639626*n*
$\log \tan^2 \delta$	3.5107897
$\log \cos 2\alpha$	9.8528923*n*
log constant	2.9401389
log (2)	6.3038209*n*
$\log \tan \delta$	1.7553949
$\log \sin 3\alpha$	9.5950715*n*
log constant	2.2777678
log (3)	3.6282342*n*
$\log \tan \delta$	1.7553949
$\log \sin \alpha$	9.9663226
log constant	2.7811577*n*
log (4)	4.5028752*n*
$\log \cos 2\alpha$	9.8528923*n*
log constant	2.6391089
log (5)	2.4920012*n*
$\log \tan \delta$	1.7553949
$\log \cos \alpha$	9.5786708*n*
log constant	0.8598285*n*
log (6)	2.1938942
$\log \tan^2 \delta$	3.5107897
$\log \sin 2\alpha$	9.8460234*n*
log constant	1.2248167*n*
log (7)	4.5816298
$\log \sin 2\alpha$	9.8460234*n*
log constant	0.9237867
log (8)	0.7698101*n*

By Hill's Formulæ.

$\log \cos 2\alpha$	9.8528923*n*
log constant	2.6391089
log (1)	2.4920012*n*
$\log \sin 2\alpha$	9.8460234*n*
log constant	0.9237867*n*
log (2)	0.7698101
$\log \sin \alpha$	9.9663226
$\log \tan \delta$	1.7553949
log constant	2.6176279*n*
log (3)	4.3393454*n*
$\log \sin \alpha$	9.9663226
$\log \cos 2\alpha$	9.8528923*n*
$\log \tan \delta$	1.7553949
log constant	2.5787978
log (4)	4.1534076*n*
$\log \cos \alpha$	9.5786708*n*
$\log \tan \delta$	1.7553949
log constant	0.8598285*n*
log (5)	2.1938942
$\log \cos 2\alpha$	9.8528923*n*
$\log \tan^2 \delta$	3.5107897
log constant	2.9401389
log (6)	6.3038209*n*
$\log \sin 2\alpha$	9.8460234*n*
$\log \tan^2 \delta$	3.5107897
log constant	1.2248167*n*
log (7)	4.5816298
$\log \sin \alpha$	9.9663226
$\log \tan^3 \delta$	5.2661846
log constant	2.4027065
log (8)	7.6352137
$\log \sin \alpha$	9.9663226
$\log \cos 2\alpha$	9.8528923*n*
$\log \tan^3 \delta$	5.2661846
log constant	2.7037365
log (9)	7.7891360*n*

By Tiele's Formulæ.

$\log \sin \alpha$		9.9663226
$\log \cos \alpha$		9.5786708*n*
log constant		1.2248167*n*
log (1)		0.7698101
$\log \cos^2 \alpha$		9.1573416
log constant		2.9401389
log (2)		2.0974805
constant	−	.0000000290
(1)	+	59
(2)	+	125
P	−	.0000000106

$\log \cos \alpha$		9.5786708*n*
log constant		0.0816772*n*
log (3)		9.6603480
$\log \sin \alpha$		9.9663226
log constant		2.8996767*n*
log (4)		2.8659993*n*
$\log \cos^2 \alpha$		9.1573416
$\log \sin \alpha$		9.9663226
log constant		2.8798278
log (5)		2.0034920
(3)	+	.000000000046
(4)	−	73451
(5)	+	10081
P_1	−	.000000063324

$\log P_1$	2.8015683*n*
$\log \tan \delta$	1.7553949
$\log P_1 \tan \delta$	4.5569632*n*

$\log \sin \alpha$		9.9663226
$\log \cos \alpha$		9.5786708*n*
log constant		1.5258467*n*
log (6)		1.0708401
$\log \cos^2 \alpha$		9.1573416
log constant		3.2411689
log (7)		2.3985105
constant	−	.00000008712
(6)	+	118
(7)	+	2503
P_2	−	.00000006091

$\log P_2$	2.7846886*n*
$\log \tan^2 \delta$	3.5107897
$\log P_2 \tan^2 \delta$	6.2954783*n*

$\log \cos^2 \alpha$		9.1573416
$\log \sin \alpha$		9.9663226
log constant		3.0047665
log (8)		2.1284307
$\log \sin \alpha$		9.9663226
log constant		2.4027065*n*
log (9)		2.3690291*n*
(8)	+	.000000013441
(9)	−	.000000023390
P_3	−	.000000009949

$\log P_3$	1.9977794*n*
$\log \tan^3 \delta$	5.2661846
$\log P_3 \tan^3 \delta$	7.2639640*n*

		s.
Constant	+	0.0000000145
(1)	−	18363802
(2)	−	2012894
(3)	−	4248
(4)	−	31833
(5)	−	310
(6)	+	156
(7)	+	38162
(8)	+	6
$\frac{d^3\alpha}{dt^3}$	−	0.0020374618

		s.
Constant	+	0.0000000145
(1)	−	310
(2)	+	6
(3)	−	21844
(4)	−	14237
(5)	+	156
(6)	−	2012894
(7)	+	38162
(8)	+	43173149
(9)	−	61536957
	−	0.0020374624

		s.
P	−	0.0000000106
$P_1 \tan \delta$	−	36055
$P_2 \tan^2 \delta$	−	1974596
$P_3 \tan^3 \delta$	−	18363861
	−	0.0020374618

Computation of $\frac{d^3\delta}{dt^3}$:

By Bessel's Formulæ.

log $\tan^2\delta$	3.5107897
log $\sin^2\alpha$	9.9326452
log $\cos\alpha$	9.5786708n
log constant	3.7548891n
log (1)	6.7769948
log $\tan\delta$	1.7553949
log $\sin\alpha$	9.9663226
log $\cos\alpha$	9.5786708n
log constant	4.1162302n
log (2)	5.4166185
log $\cos\alpha$	9.5786708n
log constant	4.0757367n
log (3)	3.6544075
log $\cos^3\alpha$	8.7360124n
log constant	3.2777678
log (4)	2.0137802n
log $\sin\alpha$	9.9663226
log constant	2.0359378
log (5)	2.0022604
log $\sin^2\alpha$	9.9326452
log $\tan\delta$	1.7553949
log constant	2.4009130
log (6)	4.0889531

		″
(1)	+	0.00059840
(2)	+	2610
(3)	+	45
(4)	−	1
(5)	+	1
(6)	+	123
$\frac{d^3\delta}{dt^3}$	+	0.00062618

By Hill's Formulæ.

log $\sin\alpha$	9.9663226
log constant	2.0359378
log (1)	2.0022604
log $\cos\alpha$	9.5786708n
log constant	4.0004500n
log (2)	3.5791208
log $\sin^2\alpha$	9.9326452
log $\cos\alpha$	9.5786708n
log constant	3.2777678n
log (3)	2.7890838
log $\sin^2\alpha$	9.8460234n
log $\tan\delta$	1.7553949
log constant	3.8152002n
log (4)	5.4166185
log $\sin^2\alpha$	9.9326452
log $\tan\delta$	1.7553949
log constant	2.4009130
log (5)	4.0889531
log $\sin^2\alpha$	9.9326452
log $\cos\alpha$	9.5786708n
log $\tan^2\delta$	3.5107897
log constant	3.7548891n
log (6)	6.7769948

		″
(1)	+	0.00000001
(2)	+	38
(3)	+	6
(4)	+	2610
(5)	+	123
(6)	+	59840
$\frac{d^3\delta}{dt^3}$	+	0.00062618

By Tiele's Formulæ.

log $\sin\alpha$	9.9663226
log constant	2.0359378
log (1)	2.0022604
log $\cos\alpha$	9.5786708n
log constant	4.0004500n
log (2)	3.5791208
log $\sin^2\alpha$	9.9326452
log $\cos\alpha$	9.5786708n
log constant	3.2777678n
log (3)	2.7890838
(1)	+ .000000010
(2)	+ 379
(3)	+ 62
Q	+ .000000451
log $\sin^2\alpha$	9.9326452
log constant	2.4009130
log (4)	2.3335582
log $\sin\alpha$	9.9663226
log $\cos\alpha$	9.5786708n
log constant	4.1162302n
log (5)	3.6612236

(4)	+.000000021555
(5)	+ 458378
Q_1	+.000000479933
log Q_1	3.6811806
log $\tan\delta$	1.7553949
log $Q_1\tan\delta$	5.4365755
log $\sin^2\alpha$	9.9326452
log $\cos\alpha$	9.5786708n
log constant	3.7548891n
log Q_2	3.2662051n
log $\tan^2\delta$	3.5107897
log $Q_2\tan^2\delta$	6.7769948

		″
Q	+	0.00000045
$Q_1\tan\delta$	+	2733
$Q_2\tan^2\delta$	+	59840
$\frac{d^3\delta}{dt^3}$	+	0.00062618

Computation of $\frac{d^4\alpha}{dt^4}$ and $\frac{d^4\delta}{dt^4}$:

By Bessel's Formulæ.

$\frac{d^4\alpha}{dt^4}$

log $\tan^4\delta$	7.0215795
log sin 4 α	9.9999457
log constant	$\bar{8}$.8676086
log (1)	5.8891338
log $\tan^3\delta$	5.2661846
log cos 3 α	9.9634456
log constant	$\bar{9}$.5299797
log (2)	4.7596099
log $\tan^2\delta$	3.5107897
log sin 4 α	9.9999457
log constant	$\bar{8}$.8676086
log (3)	2.3783440
log $\tan^2\delta$	3.5107897
log sin 2 α	9.8460234*n*
log constant	$\bar{9}$.6330799*n*
log (4)	2.9898930
log tan δ	1.7553949
log cos 3 α	9.9634456
log constant	$\bar{9}$.4050410
log (5)	1.1238815
log tan δ	1.7553949
log cos α	9.5786708*n*
log constant	$\bar{8}$.9667501*n*
log (6)	0.3008158
log sin 4 α	9.9999457
log constant	$\bar{\bar{7}}$.9645186
log (7)	$\bar{\bar{7}}$.9644643
log sin 2 α	9.8460234*n*
log constant	$\bar{9}$.3320498*n*
log (8)	$\bar{9}$.1780732

$\frac{d^4\delta}{dt^4}$

log $\tan^3\delta$	5.2661846
log $\sin^4\alpha$	9.8652904
log constant	$\bar{9}$.7426700
log (1)	4.8741450
log $\tan^3\delta$	5.2661846
log $\sin^2\alpha$	9.9326452
log $\cos^2\alpha$	9.1573416
log constant	0.3447299*n*
log (2)	4.7009013*n*
log $\tan^2\delta$	3.5107897
log sin α	9.9663226
log constant	0.4050411
log (3)	3.8821534
log $\tan^2\delta$	3.5107897
log sin α	9.9663226
log $\cos^2\alpha$	9.1573416
log constant	0.8821623
log (4)	3.5166162
log tan δ	1.7553949
log $\sin^2\alpha$	9.9326452
log constant	0.8333289
log (5)	2.5213690
log tan δ	1.7553949
log constant	0.4653522*n*
log (6)	2.2207471*n*
log tan δ	1.7553949
log $\sin^4\alpha$	9.8652904
log constant	$\bar{9}$.2655487
log (7)	0.8862340

log tan δ	1.7553949
log $\sin^2\alpha$	9.9326452
log $\cos^2\alpha$	9.1573416
log constant	0.1686387*n*
log (8)	1.0140204*n*
log sin α	9.9663226
log constant	0.4248824
log (9)	0.3912050
log sin α	9.9663226
log $\cos^2\alpha$	9.1573416
log constant	0.4050411*n*
log (10)	$\bar{9}$.5287053*n*

		s.
(1)	+	0.00007747004
(2)	+	574923
(3)	+	2389
(4)	+	9770
(5)	+	133
(6)	+	20
(7)	+	0
(8)	+	1
$\frac{d^4\alpha}{dt^4}=$		+0.00008334240

		″
(1)	+	0.0000074842
(2)	−	50223
(3)	+	7624
(4)	+	3286
(5)	+	332
(6)	−	166
(7)	+	8
(8)	−	10
(9)	+	2
(10)	−	0
$\frac{d^4\delta}{dt^4}=$		+0.0000035695

It will be found convenient to represent the entire coefficients of $(t'-t_0)$, $(t'-t_0)^2$, $(t'-t_0)^3$, $(t'-t_0)^4$, &c., in equations (14) and (15) by a single expression.

Let
$$U^{\mathrm{I}} = \frac{d\alpha}{dt} \qquad \text{and} \qquad W^{\mathrm{I}} = \frac{d\delta}{dt}$$
$$U^{\mathrm{II}} = \frac{1}{2}\frac{d^2\alpha}{dt^2} \qquad\qquad W^{\mathrm{II}} = \frac{1}{2}\frac{d^2\delta}{dt^2}$$
$$U^{\mathrm{III}} = \frac{1}{2.3}\frac{d^3\alpha}{dt^3} \qquad\qquad W^{\mathrm{III}} = \frac{1}{2.3}\frac{d^3\delta}{dt^3}$$
$$U^{\mathrm{IV}} = \frac{1}{2.3.4}\frac{d^4\alpha}{dt^4} \qquad\qquad W^{\mathrm{IV}} = \frac{1}{2.3.4}\frac{d^4\delta}{dt^4}$$
&c., &c.

Then writing t for $(t'-t_0)$ we have,

$$\alpha = \alpha_0 + U^{\mathrm{I}} t + U^{\mathrm{II}} t^2 + U^{\mathrm{III}} t^3 + U^{\mathrm{IV}} t^4, \text{ \&c.} \qquad (48)$$

$$\delta = \delta_0 + W^{\mathrm{I}} t + W^{\mathrm{II}} t^2 + W^{\mathrm{III}} t^3 + W^{\mathrm{IV}} t^4, \text{ \&c.} \qquad (49)$$

We now compute the right ascension of Groombridge 1119 for $t = -20$, -40, -80, -120, corresponding to the years 1855, 1835, 1795, and 1755.

With the data

$$\frac{d\alpha}{dt} = +73\overset{s.}{.}514324 \qquad \frac{d^2\alpha}{dt^2} = -\overset{s.}{.}30237888 \qquad \frac{d^3\alpha}{dt^3} = -\overset{s.}{.}0020374621 \qquad \frac{d^4\alpha}{dt^4} = +\overset{s.}{.}00008334240$$

and the values of

$$U^{\mathrm{I}} = 73\overset{s.}{.}514324 \qquad U^{\mathrm{II}} = -\overset{s.}{.}15118944 \qquad U^{\mathrm{III}} = -\overset{s.}{.}000339577 \qquad U^{\mathrm{IV}} = +\overset{s.}{.}0000034726$$

we have,

		For 1855.	**For 1835.**	**For 1795.**	**For 1755.**
		h m. s.	h. m. s.	h. m. s.	h. m. s.
α_0	=	7 29 5.6310	7 29 5.6310	7 29 5.6310	7 29 5.6310
$U^{\mathrm{I}}\ t$	−	24 30.2865	− 49 0.5730	−1 38 1.1459	−2 27 1.7189
$U^{\mathrm{II}}\ t^2$	−	1 0.4758	− 4 1.9031	− 16 7.6124	− 36 17.1279
$U^{\mathrm{III}}\ t^3$	+	2.7166	+ 21.7329	+ 2 53.8634	+ 9 46.7890
$U^{\mathrm{IV}}\ t^4$	+	0.5556	+ 8.8899	+ 2 22.2377	+ 12 0.0783
α		7 3 38.1409	6 36 33.7778	5 40 12.9738	4 47 33.6515

The corresponding values of α obtained from equations (6) are:

h. m. s.	h. m. s.	h. m. s.	h. m. s.
7 3 38.153	6 36 34.034	5 40 10.397	4 45 55.203

giving the deviations

$$+0\overset{s.}{.}012 \qquad +0\overset{s.}{.}256 \qquad -2\overset{s.}{.}577 \qquad -98\overset{s.}{.}449$$

It will be seen from this example, that, at the end of twenty years, equation (48) to the third term inclusive fails by $0^s.56$; but that when the fourth term is included, the place by equation (48) is reproduced within about $0^s.01$. For any time greater than twenty years, terms involving higher powers of t will be required in order to obtain a correspondence with the results given by equations (6).

Computation of the Differential Coefficients from Successive Orders of Differences of the given Functions.

Let Δ_1, Δ_2, Δ_3, &c., represent the successive orders of differences of the computed functions.

Let Δ^{I}, Δ^{II}, Δ^{III}, &c., represent the differences opposite the initial function.

For the odd differences,

$$\Delta^{\mathrm{I}} = \frac{\Delta_1^{+\frac{1}{2}} + \Delta_1^{-\frac{1}{2}}}{2}, \quad \Delta^{\mathrm{III}} = \frac{\Delta_3^{+\frac{1}{2}} + \Delta_3^{-\frac{1}{2}}}{2}, \quad \Delta^{\mathrm{V}} = \frac{\Delta_5^{+\frac{1}{2}} + \Delta_5^{-\frac{1}{2}}}{2}, \quad \text{\&c.}$$

For the even differences,

$$\Delta^{\mathrm{II}} = \Delta_2, \quad \Delta^{\mathrm{IV}} = \Delta_4, \quad \Delta^{\mathrm{VI}} = \Delta_6, \quad \text{\&c.}$$

Then (see Brünnow, Spher. Astron., 1865, p. 28),

$$\begin{aligned}
\frac{d\alpha}{dt} &= \frac{1}{w}\left[\Delta^{\mathrm{I}} - \tfrac{1}{6}\Delta^{\mathrm{III}} + \tfrac{1}{30}\Delta^{\mathrm{V}} - \tfrac{1}{140}\Delta^{\mathrm{VII}} + \tfrac{1}{630}\Delta^{\mathrm{IX}} - \text{\&c.}\right]\\
\frac{d^2\alpha}{dt^2} &= \frac{1}{w^2}\left[\Delta^{\mathrm{II}} - \tfrac{1}{12}\Delta^{\mathrm{IV}} + \tfrac{1}{90}\Delta^{\mathrm{VI}} - \tfrac{1}{560}\Delta^{\mathrm{VIII}} + \tfrac{1}{3150}\Delta^{\mathrm{X}} - \text{\&c.}\right]\\
\frac{d^3\alpha}{dt^3} &= \frac{1}{w^3}\left[\Delta^{\mathrm{III}} - \tfrac{1}{4}\Delta^{\mathrm{V}} + \tfrac{7}{120}\Delta^{\mathrm{VII}} - \tfrac{41}{3024}\Delta^{\mathrm{IX}} + \text{\&c.}\right]\\
\frac{d^4\alpha}{dt^4} &= \frac{1}{w^4}\left[\Delta^{\mathrm{IV}} - \tfrac{1}{6}\Delta^{\mathrm{VI}} + \tfrac{7}{240}\Delta^{\mathrm{VIII}} - \tfrac{41}{7560}\Delta^{\mathrm{X}} + \text{\&c.}\right]\\
\frac{d^5\alpha}{dt^5} &= \frac{1}{w^5}\left[\Delta^{\mathrm{V}} - \tfrac{1}{3}\Delta^{\mathrm{VII}} + \tfrac{13}{144}\Delta^{\mathrm{IX}} - \text{\&c.}\right]\\
\frac{d^6\alpha}{dt^6} &= \frac{1}{w^6}\left[\Delta^{\mathrm{VI}} - \tfrac{1}{4}\Delta^{\mathrm{VIII}} + \tfrac{13}{240}\Delta^{\mathrm{X}} - \text{\&c.}\right]\\
\frac{d^7\alpha}{dt^7} &= \frac{1}{w^7}\left[\Delta^{\mathrm{VII}} - \tfrac{5}{12}\Delta^{\mathrm{IX}} + \text{\&c.}\right]\\
\frac{d^8\alpha}{dt^8} &= \frac{1}{w^8}\left[\Delta^{\mathrm{VIII}} - \tfrac{1}{3}\Delta^{\mathrm{X}} + \text{\&c.}\right]\\
\frac{d^9\alpha}{dt^9} &= \frac{1}{w^9}\left[\Delta^{\mathrm{IX}} - \text{\&c.}\right]\\
\frac{d^{10}\alpha}{dt^{10}} &= \frac{1}{w^{10}}\left[\Delta^{\mathrm{X}} - \text{\&c.}\right]
\end{aligned} \tag{50}$$

The following cases occur in which this method of development is applicable:

Case	Given	From	To find
(*a*)	α	α	$\frac{d\alpha}{dt}$ $\frac{d^2\alpha}{dt^2}$ $\frac{d^3\alpha}{dt^3}$ $\frac{d^4\alpha}{dt^4}$ $\frac{d^5\alpha}{dt^5}$, &c.
(*b*)	α $\frac{d\alpha}{dt}$	$\frac{d\alpha}{dt}$	$\frac{d^2\alpha}{dt^2}$ $\frac{d^3\alpha}{dt^3}$ $\frac{d^4\alpha}{dt^4}$ $\frac{d^5\alpha}{dt^5}$ $\frac{d^6\alpha}{dt^6}$, &c.
(*c*)	α $\frac{d\alpha}{dt}$ $\frac{d^2\alpha}{dt}$	$\frac{d^2\alpha}{dt^2}$	$\frac{d^2\alpha}{dt^3}$ $\frac{d^4\alpha}{dt^4}$ $\frac{d^5\alpha}{dt^5}$ $\frac{d^6\alpha}{dt^6}$ $\frac{d^7\alpha}{dt^7}$, &c.
(*d*)	α $\frac{d\alpha}{dt}$ $\frac{d^2\alpha}{dt^2}$ $\frac{d^3\alpha}{dt^3}$	$\frac{d^3\alpha}{dt^3}$	$\frac{d^4\alpha}{dt^4}$ $\frac{d^5\alpha}{dt^5}$ $\frac{d^6\alpha}{dt^6}$ $\frac{d^7\alpha}{dt^7}$ $\frac{d^8\alpha}{dt^8}$, &c.
(*e*)	α $\frac{d\alpha}{dt}$ $\frac{d^2\alpha}{dt^2}$ $\frac{d^3\alpha}{dt^3}$ $\frac{d^4\alpha}{dt^4}$	$\frac{d^4\alpha}{dt^4}$	$\frac{d^5\alpha}{dt^5}$ $\frac{d^6\alpha}{dt^6}$ $\frac{d^7\alpha}{dt^7}$ $\frac{d^8\alpha}{dt^8}$ $\frac{d^9\alpha}{dt^9}$, &c.

and similarly for δ, $\frac{d\delta}{dt}$, $\frac{d^2\delta}{dt^2}$, &c.

For the application of this method in the computation of the differential coefficients of Groombridge 1119 we have the following data, for 1, 8, and 16 years.

CASE (*a*). INITIAL FUNCTION = α.

FOR $w = 1$.

	h.	m.	s.	Δ_1	Δ_2	Δ_3	Δ_4	
1871.0	7	24	9.177					
				+ 1 14.560				
1872.0	7	25	23.737		− .297			
				+ 1 14.263		+ .000		
1873.0	7	26	38.000		− .297		− .004	
				+ 1 13.966		− .004		
1874.0	7	27	51.966		− .301		+ .003	
				+ 1 13.665		− .001		
1875.0	7	29	5.631		− .302		− .002	+ .000
				+ 1 13.363		− .003		
1876.0	7	30	18.994		− .305		+ .002	
				+ 1 13.058		− .001		
1877.0	7	31	32.052		− .306		− .001	
				+ 1 12.752		− .002		
1878.0	7	32	44.804		− .308			
				+ 1 12.444				
1879.0	7	33	57.248					

CASE (*a*). INITIAL FUNCTION = α.

FOR $w = 8$.

	h.	m.	s.	Δ_1	Δ_2	Δ_3	Δ_4	Δ_5	Δ_6	Δ_7	
1827.0	6	25	25.071								
				+11 8.963							
1835.0	6	36	34.034		− 9.772						
				+10 59.191		−2.571					
1843.0	6	47	33.225		−12.343		+.308				
				+10 46.848		−2.263		+.030			
1851.0	6	58	20.073		−14.606		+.338		−.018		
				+10 32.242		−1.925		+.012		+.014	
1859.0	7	8	52.315		−16.531		+.350		−.004		
				+10 15.711		−1.575		+.008		−.023	
1867.0	7	19	8.026		−18.106		+.358		−.027		
				+ 9 57.605		−1.217		−.019		+.020	
1875.0	7	29	5.631		−19.323		+.339		−.007		+.002
				+ 9 38.282		− .878		−.026		+.006	
1883.0	7	38	43.913		−20.201		+.313		−.001		
				+ 9 18.081		− .565		−.027		−.009	
1891.0	7	48	1.994		−20.766		+.286		−.010		
				+ 8 57.315		− .279		−.037		+.007	
1899.0	7	56	59.309		−21.045		+.249		−.003		
				+ 8 36.270		− .030		−.040			
1907.0	8	5	35.579		−21.075		+.209				
				+ 8 15.195		+ .179					
1915.0	8	13	50.774		−20.896						
				+ 7 54.299							
1923.0	8	21	45.073								

CASE (*a*). INITIAL FUNCTION = α.

FOR $w = 16$.

	h.	m.	s.	Δ_1	Δ_2	Δ_3	Δ_4	Δ_5	Δ_6	Δ_7	Δ_8	Δ_9	Δ_{10}
1795.0	5	40	10.397										
				+22 38.936									
1811.0	6	2	49.333		− 3.198								
				+22 35.738		−24.386							
1827.0	6	25	25.071		−27.584		+2.906						
				+22 8.154		−21.480		+1.864					
1843.0	6	47	33.225		−49.064		+4.770		−1.103				
				+21 19.090		−16.710		+ .761		+.165			
1859.0	7	8	52.315		−65.774		+5.531		− .938		+.108		
				+20 13.316		−11.179		− .177		+.273		−.022	
1875.0	7	29	5.631		−76.953		+5.354		− .665		+.086		−.094
				+18 56.363		− 5.825		− .842		+.359		−.116	
1891.0	7	48	1.994		−82.778		+4.512		− .306		−.030		
				+17 33.585		− 1.313		−1.148		+.329			
1907.0	8	5	35.579		−84.091		+3.364		+ .023				
				+16 9.494		+ 2.051		−1.125					
1923.0	8	21	45.073		−82.040		+2.239						
				+14 47.454		+ 4.290							
1939.0	8	36	32.527		−77.750								
				+13 29.704									
1955.0	8	50	2.231										

CASE (*b*). INITIAL FUNCTION $= \frac{d\alpha}{dt}$.

FOR $w = 1$.

		Δ_1	Δ_2	Δ_3	Δ_4	
1871.0	+ 74.705491					
		− 294443				
1872.0	+ 74.411048		− 2294			
		− 296737		+ 97		
1873.0	+ 74.114311		− 2197		− 9	
		− 298934		+ 78		
1874.0	+ 73.815377		− 2119		− 1	
		− 301053		+ 77		
1875.0	+ 73.514324		− 2042		+ 12	+ 0
		− 303095		+ 89		
1876.6	+ 73.211229		− 1953		− 8	
		− 305048		+ 81		
1877.0	+ 72.906181		− 1872		+ 6	
		− 306920		+ 87		
1878.0	+ 72.599261		− 1785			
		− 308705				
1879.0	+ 72.290556					

CASE (*b*). INITIAL FUNCTION $= \frac{d\alpha}{dt}$.

FOR $w = 8$.

		Δ_1	Δ_2	Δ_3	Δ_4	Δ_5	Δ_6	Δ_7	Δ_8
1843.0	+ 81.667645								
		− 1.688364							
1851.0	+ 79.979281		− .262517						
		− 1.950881		+ 43548					
1859.0	+ 78.028400		− .218969		+ 1045				
		− 2.169850		+ 44593		− 2037			
1867.0	+ 75.858550		− .174376		− 992		+ 514		
		− 2.344226		+ 43601		− 1523		− 20	
1875.0	+ 73.514324		− .130775		− 2515		+ 494		− 135
		− 2.475001		+ 41086		− 1029		− 155	
1883.0	+ 71.039323		− .089689		− 3544		+ 339		
		− 2.564690		+ 37542		− 690			
1891.0	+ 68.474633		− .052147		− 4234				
		− 2.616837		+ 33308					
1899.0	+ 65.857796		− .018839						
		− 2.635676							
1907.0	+ 63.222120								

CASE (*b*). INITIAL FUNCTION $= \dfrac{d\alpha}{dt}$.

FOR $w = 16$.

	s.	Δ_1	Δ_2	Δ_3	Δ_4	Δ_5	Δ_6	Δ_7	Δ_8
1811.0	+85.071302								
		−0.972057							
1827.0	+84.099245		−1.459543						
		−2.431600		+.251898					
1843.0	+81.667645		−1.207645		+80916				
		−3.639245		+.332814		−64514			
1859.0	+78.028400		− .874831		+16402		+11689		
		−4.514076		+.349216		−52825		+11973	
1875.0	+73.514324		− .525615		−36423		+23662		−13890
		−5.039691		+.312793		−29163		− 1917	
1891.0	+68.474633		− .212822		−65586		+21745		
		−5.252513		+.247207		− 7418			
1907.0	+63.222120		+ .034385		−73004				
		−5.218128		+.174203					
1923.0	+58.003992		+ .208588						
		−5.009540							
1939.0	+52.994452								

CASE (*c*). INITIAL FUNCTION $= \dfrac{d^2\alpha}{dt^2}$.

FOR $w = 1$.

	s.	Δ_1	Δ_2	Δ_3	Δ_4
1871.0	− 0.29354576				
		− 233529			
1872.0	− 0.29880105		+ 8503		
		− 225026		− 53	
1873.0	− 0.29813131		+ 8450		− 2
		− 216576		− 55	
1874.0	− 0.30029707		+ 8395		− 1
		− 208181		− 56	
1875.0	− 0.30237888		+ 8339		− 11
		− 199842		− 67	
1876.0	− 0.30437730		+ 8272		− 7
		− 191570		− 74	
1877.0	− 0.30629300		+ 8198		+ 0
		− 183372		− 74	
1878.0	− 0.30812672		+ 8124		
		− 175248			
1879.0	− 0.30987920				

CASE (*c*). INITIAL FUNCTION $= \dfrac{d^2\alpha}{dt^2}$.

FOR $w = 8$.

	s.	Δ_1	Δ_2	Δ_3	Δ_4	Δ_5	Δ_6	Δ_7	Δ_8
1843.0	− 0.19318438								
		− 3544774							
1851.0	− 0.22863212		+ 531344						
		− 3013430		+ 24218					
1859.0	− 0.25876642		+ 555562		− 25290				
		− 2457868		− 1072		+ 4005			
1867.0	− 0.28334510		+ 554490		− 21285		+ 947		
		− 1903378		− 22357		+ 4952		− 782	
1875.0	− 0.30237888		+ 532133		− 16333		+ 165		+ 274
		− 1371245		− 38690		+ 5117		− 508	
1883.0	− 0.31609133		+ 493443		− 11216		− 343		
		− 877802		− 49906		+ 4774			
1891.0	− 0.32486935		+ 443537		− 6442				
		− 434265		− 56348					
1899.0	− 0.32921200		+ 387189						
		− 47076							
1907.0	− 0.32968276								

CASE (*c*). INITIAL FUNCTION $= \dfrac{d^2\alpha}{dt^2}$.

FOR $w = 16$.

	s.	Δ_1	Δ_2	Δ_3	Δ_4	Δ_5	Δ_6	Δ_7	Δ_8
1811.0	−0.01260433								
		−9609612							
1827.0	−0.10870045		+1161219						
		−8448393		+728970					
1843.0	−0.19318438		+1890189		−422201				
		−6558204		+306769		+ 30673			
1859.0	−0.25876642		+2196958		−391528		+101121		
		−4361246		− 84759		+131794		−80033	
1875.0	−0.30237888		+2112199		−259734		+ 20088		+24336
		−2249047		−344493		+151882		−55697	
1891.0	−0.32486935		+1767706		−107852		− 35609		
		− 481341		−452345		+116273			
1907.0	−0.32968276		+1315361		+ 8421				
		+ 834020		−443924					
1923.0	−0.32134256		+ 871437						
		+1705457							
1939.0	−0.30428799								

CASE (*d*). INITIAL FUNCTION $= \frac{d^3 \alpha}{d t^3}$.

FOR $w = 1$.

	s.	Δ_1	Δ_2	Δ_3	Δ_4	
1871.0	− 0.0023754634					
		+ 852882				
1872.0	− 0.0022901752		− 4971			
		+ 847911		− 425		
1873.0	− 0.0022053841		− 5396		+ 11	
		+ 842515		− 414		
1874.0	− 0.0021211326		− 5810		+ 13	
		+ 836705		− 401		
1875.0	− 0.0020374621		− 6211		+ 12	+ 12
		+ 830494		− 389		
1876.0	− 0.0019544127		− 6600		+ 11	
		+ 823894		− 378		
1877.0	− 0.0018720233		− 6978		+ 13	
		+ 816916		− 365		
1878.0	− 0.0017903317		− 7343			
		+ 809573				
1879.0	− 0.0017093744					

CASE (*d*). INITIAL FUNCTION $= \frac{d^3 \alpha}{d t^3}$.

FOR $w = 8$.

	s.	Δ_1	Δ_2	Δ_3	Δ_4	Δ_5	Δ_6	Δ_7	Δ_8
1843.0	−0.0047421960								
		+6377656							
1851.0	−0.0041044304		+472678						
		+6850334		−335216					
1859.0	−0.0034193970		+137462		+41511				
		+6987796		−293705		+16005			
1867.0	−0.0027206174		−156243		+57516		−9284		
		+6831553		−236189		+ 6721		+1213	
1875.0	−0.0020374621		−392432		+64237		−8071		+1823
		+6439121		−171952		− 1350		+3036	
1883.0	−0.0013935500		−564384		+62887		−5035		
		+5874737		−109065		− 6385			
1891.0	−0.0008060763		−673449		+56502				
		+5201388		− 52563					
1899.0	−0.0002859375		−726012						
		+4475376							
1907.0	+0.0001616001								

CASE (*d*). INITIAL FUNCTION $= \dfrac{d^3\alpha}{dt^3}$.

FOR $w = 16$.

	s.	Δ_1	Δ_2	Δ_3	Δ_4	Δ_5	Δ_6	Δ_7	Δ_8
1811.0	−0.0061613944								
		+ 4345993							
1827.0	−0.0057367951		+5599998						
		+ 9945991		−2317999					
1843.0	−0.0047421960		+3281999		−372641				
		+13227990		−2690640		+966431			
1859.0	−0.0034193970		+ 591359		+593790		−594974		
		+13819349		−2096850		+371457		+132217	
1875.0	−0.0020374621		−1505491		+965247		−462757		+110012
		+12313858		−1131603		− 91300		+242229	
1891.0	−0.0008060763		−2637094		+873947		−220528		
		+ 9676764		− 257656		−311828			
1907.0	+0.0001616001		−2894750		+562119				
		+ 6782014		+ 304463					
1923.0	+0.0008398015		−2590287						
		+ 4191727							
1939.0	+0.0012589742								

CASE (*e*). INITIAL FUNCTION $= \dfrac{d^4\alpha}{dt^4}$.

FOR $w = 1$.

	s.	Δ_1	Δ_2	Δ_3	Δ_4	
1871.0	+ 0.00008548692					
		− 47054				
1872.0	+ 0.00008501638		− 4482			
		− 51536		+ 165		
1873.0	+ 0.00008450102		− 4317		− 4	
		− 55853		+ 161		
1874.0	+ 0.00008394249		− 4156		− 2	
		− 60009		+ 159		
1875.0	+ 0.00008334240		− 3997		− 1	+ 1
		− 64006		+ 158		
1876.0	+ 0.00008270234		− 3839		+ 3	
		− 67845		+ 161		
1877.0	+ 0.00008202389		− 3678		+ 7	
		− 71523		+ 168		
1878.0	+ 0.00008130866		− 3510			
		− 75033				
1879.0	+ 0.00008055833					

CASE (*e*). INITIAL FUNCTION $= \frac{d^4 \alpha}{d t^4}$.

FOR $w = 8$.

	s.	Δ_1	Δ_2	Δ_3	Δ_4	Δ_5	Δ_6	Δ_7	Δ_8
1843.0	+0.00007522783								
		+811510							
1851.0	+0.00008334293		−435399						
		+376111		+37978					
1859.0	+0.00008710404		−397421		+25899				
		− 21310		+63877		−11902			
1867.0	+0.00008689094		−333544		+13997		+ 950		
		−354854		+77874		−10952		+1496	
1875.0	+0.00008334240		−255670		+ 3045		+2446		−898
		−610524		+80919		− 8506		+ 598	
1883.0	+0.00007723716		−174751		− 5461		+3004		
		−785275		+75458		− 5502			
1891.0	+0.00006938441		− 99293		−10963				
		−884568		+64495					
1899.0	+0.00006053873		− 34798						
		−919366							
1907.0	+0.00005134507								

CASE (*e*). INITIAL FUNCTION $= \frac{d^4 \alpha}{d t^4}$.

FOR $w = 16$.

	s.	Δ_1	Δ_2	Δ_3	Δ_4	Δ_5	Δ_6	Δ_7	Δ_8
1811.0	+0.00000543240								
		+4088210							
1827.0	+0.00004631450		−1196877						
		+2891333		−506835					
1843.0	+0.00007522783		−1703712		+646762				
		+1187621		+139927		−242539			
1859.0	+0.00008710404		−1563785		+404223		− 94334		
		− 376164		+544150		−336873		+210497	
1875.0	+0.00008334240		−1019635		+ 67350		+116163		−165015
		−1395799		+611500		−220710		+ 45482	
1891.0	+0.00006938441		− 408135		−153360		+161645		
		−1803934		+458140		− 59065			
1907.0	+0.00005134507		+ 50005		−212425				
		−1753929		+245715					
1923.0	+0.00003380578		+ 295720						
		−1458209							
1939.0	+0.00001922369								

For an illustration of the application of formulæ (50), and the subsequent computation of the terms U^{II}, U^{III}, &c., we select case (*b*) and case (*e*), in each of which $w = 16$.

CASE (*b*).

	s.
Δ^{I}	-4.776884
$-\frac{1}{6}\Delta^{III}$	-0.055167
$+\frac{1}{30}\Delta^{V}$	-0.001366
$-\frac{1}{140}\Delta^{VII}$	-0.000036
sum	-4.833453
log sum	$0.6842575n$
log 16	1.2041200
$\log\frac{d^2\alpha}{dt^2}$	$9.4801375n$
log 2	0.3010300
$\log U^{II}$	$9.1791075n$
U^{II}	-0.151045

	s.
Δ^{II}	-0.525615
$-\frac{1}{12}\Delta^{IV}$	$+0.003035$
$+\frac{1}{90}\Delta^{VI}$	$+0.000263$
$-\frac{1}{560}\Delta^{VIII}$	$+0.000025$
sum	-0.522292
log sum	$9.7179134n$
log 16^2	2.4082400
$\log\frac{d^3\alpha}{dt^3}$	$7.3096734n$
log 6	0.7781513
$\log U^{III}$	$6.5315221n$
U^{III}	-0.00034003

	s.
Δ^{III}	$+0.331004$
$-\frac{1}{4}\Delta^{V}$	$+0.010248$
$+\frac{7}{120}\Delta^{VII}$	$+0.000293$
sum	$+0.341545$
log sum	9.53345
log 16^3	3.61236
$\log\frac{d^4\alpha}{dt^4}$	5.92109
log 24	1.38021
$\log U^{IV}$	4.54088
U^{IV}	$+0.0000034744$

	s.
Δ^{IV}	-0.036423
$-\frac{1}{6}\Delta^{VI}$	-0.003944
$+\frac{7}{240}\Delta^{VIII}$	-0.000405
sum	-0.040772
log sum	$8.61036n$
log 16^4	4.81648
$\log\frac{d^5\alpha}{dt^5}$	$3.79388n$
log 120	2.07918
$\log U^{V}$	$1.71470n$
U^{V}	-0.000000005184

	s.
Δ^{V}	-0.040994
$-\frac{1}{3}\Delta^{VII}$	-0.001676
sum	-0.042670
log sum	$8.63012n$
log 16^5	6.02060
$\log\frac{d^6\alpha}{dt^6}$	$2.60952n$
log 720	2.85733
$\log U^{VI}$	$\bar{9}.75219n$
U^{VI}	-0.00000000005652

	s.
Δ^{VI}	$+0.023662$
$-\frac{1}{4}\Delta^{VIII}$	$+0.003472$
sum	$+0.027134$
log sum	8.43351
log 16^6	7.22472
$\log\frac{d^7\alpha}{dt^7}$	1.20879
log 5040	3.70243
$\log U^{VII}$	$\bar{7}.50636$
U^{VII}	$+0.0000000000003209$

Δ^{VII}	$+\overset{s.}{0}.005028$	Δ^{VIII}	$-\overset{s.}{0}.013890$
sum	$+0.005028$	sum	-0.013890
log sum	7.70140	log sum	8.14270*n*
log 16^7	8.42884	log 16^8	9.63296
$\log \frac{d^8\alpha}{dt^8}$	9.27256	$\log \frac{d^9\alpha}{dt^9}$	8.50974*n*
log 40320	4.60552	log 362880	5.55976
log U^{VIII}	$\bar{4}.66704$	log U^{IX}	$\bar{2}.94998n$
U^{VIII}	$+\overset{s.}{0}.000000000000000464$	U^{IX}	$-\overset{s.}{0}.00000000000000000891$

CASE (*e*).

Δ^{I}	$-\overset{s.}{0}.00000885981$	Δ^{II}	$-\overset{s.}{0}.00001019635$
$-\frac{1}{6}\Delta^{\text{III}}$	− 96304	$-\frac{1}{12}\Delta^{\text{IV}}$	− 5612
$+\frac{1}{30}\Delta^{\text{V}}$	− 9293	$+\frac{1}{90}\Delta^{\text{VI}}$	+ 1291
$-\frac{1}{140}\Delta^{\text{VII}}$	− 914	$-\frac{1}{560}\Delta^{\text{VIII}}$	+ 294
sum	-0.00000992492	sum	-0.00001023662
log sum	4.99673*n*	log sum	5.01016*n*
log 16	1.20412	log 16^2	2.40824
$\log \frac{d^5\alpha}{dt^5}$	3.79261*n*	$\log \frac{d^6\alpha}{dt^6}$	2.60192*n*
log 120	2.07918	log 720	2.85733
log U^{V}	1.71343*n*	log U^{VI}	$\bar{9}.74459n$
U^{V}	$-\overset{s.}{0}.000000005169$	U^{VI}	$-\overset{s.}{0}.00000000005554$

Δ^{III}	$+\overset{s.}{0}.00000577825$	Δ^{IV}	$+\overset{s.}{0}.00000067350$
$-\frac{1}{4}\Delta^{\text{V}}$	+ 69698	$-\frac{1}{6}\Delta^{\text{VI}}$	− 19360
$+\frac{7}{120}\Delta^{\text{VII}}$	+ 7466	$+\frac{7}{240}\Delta^{\text{VIII}}$	− 4813
sum	$+0.00000654989$	sum	$+0.00000043177$
log sum	4.81623	log sum	3.63525
log 16^3	3.61236	log 16^4	4.81648
$\log \frac{d^7\alpha}{dt^7}$	1.20387	$\log \frac{d^8\alpha}{dt^8}$	8.81877
log 5040	3.70243	log 40320	4.60552
log U^{VII}	$\bar{7}.50140$	log U^{VIII}	$\bar{4}.21325$
U^{VII}	$+\overset{s.}{0}.0000000000003173$	U^{VIII}	$+\overset{s.}{0}.000000000000000163$

	s.		s.
Δ^{V}	-0.00000278791	Δ^{VI}	$+0.00000116163$
$-\frac{1}{3}\Delta^{\mathrm{VII}}$	$-\qquad 42663$	$-\frac{1}{4}\Delta^{\mathrm{VIII}}$	$+\qquad 41254$
sum	-0.00000321454	sum	$+0.00000157417$
log sum	$4.50712n$	log sum	4.19706
$\log 16^5$	6.02060	$\log 16^6$	7.22472
$\log \frac{d^9\alpha}{dt^9}$	$8.48652n$	$\log \frac{d^{10}\alpha}{dt^{10}}$	6.97234
log 362880	5.55976	log 3628800	6.55976
$\log U^{\mathrm{IX}}$	$\bar{2}.92676n$	$\log U^{\mathrm{X}}$	$\bar{0}.41258$
	s.		s.
U^{IX}	-0.00000000000000000845	U^{X}	$+0.0000000000000000000259$

	s.		s.
Δ^{VII}	$+0.00000127989$	Δ^{VIII}	-0.00000165015
sum	$+0.00000127989$	sum	-0.00000165015
log sum	4.10718	log sum	$4.21751n$
$\log 16^7$	8.42884	$\log 16^9$	9.63296
$\log \frac{d^{11}\alpha}{dt^{11}}$	5.67834	$\log \frac{d^{12}\alpha}{dt^{12}}$	$4.58455n$
log 39916800	7.60116	log 479001600	8.68034
$\log U^{\mathrm{XI}}$	$\bar{\bar{8}}.07718$	$\log U^{\mathrm{XII}}$	$\bar{\bar{5}}.90421n$
	s.		s.
U^{XI}	$+0.000000000000000000000119$	U^{XII}	$-0.00000000000000000000000080$

The values of U^{I}, U^{II}, . . . U^{XII}, given on the following pages, were obtained from the differential coefficients derived from equations (50), employing the data given on pp. 249–256.

In the values marked by an asterisk the differential coefficients were computed as follows:—

$\frac{d\alpha}{dt}$; Bessel's Formulæ.

$\frac{d^2\alpha}{dt^2}$; Menten.

$\frac{d^3\alpha}{dt^3}$; Mean of Bessel and Hill.

$\frac{d^4\alpha}{dt^4}$; Bessel.

Separate values of the Coefficients U^{I}, U^{II}, . . . U^{XII}.

Initial Function.	U^{I}	Logarithms.
	s.	
*	+73.514324	1.8663720
α for $w = 1$	+73.51433	1.8663720
$w = 8$	+73.51464	1.8663739
$w = 16$	+73.51481	1.8663749

	U^{II}	
	s.	
*	− 0.15118944	9.1795214*n*
α for $w = 1$	− 0.151000	9.1789769*n*
$w = 8$	− 0.151182	9.1795001*n*
$w = 16$	− 0.151185	9.1795087*n*
$\frac{d\alpha}{dt}$ for $w = 1$	− 0.151030	9.1780632*n*
$w = 8$	− 0.151045	9.1791064*n*
$w = 16$	− 0.151045	9.1791064*n*

	U^{III}	
	s.	
*	− 0.000339577	6.53094*n*
α for $w = 1$	− 333	6.52244*n*
$w = 8$	− 33912	6.53035*n*
$w = 16$	− 33998	6.53145*n*
$\frac{d\alpha}{dt}$ for $w = 1$	− 34044	6.53204*n*
$w = 8$	− 34000	6.53148*n*
$w = 16$	− 34003	6.53152*n*
$\frac{d^2\alpha}{dt^2}$ for $w = 1$	− 34000	6.53148*n*
$w = 8$	− 34001	6.53149*n*
$w = 16$	− 34002	6.53150*n*

Initial Function.	U^{IV} s.	Logarithms
*	+ 0.0000034726[†]	4.54065
α for $w = 8$	+ 34605	4.53914
$w = 16$	+ 34761	4.54109
$\frac{d\alpha}{dt}$ for $w = 1$	+ 34584	4.53888
$w = 8$	+ 34714	4.54050
$w = 16$	+ 34744	4.54088
$\frac{d^2\alpha}{dt^2}$ for $w = 1$	+ 34746	4.54090
$w = 8$	+ 34732	4.54073
$w = 16$	+ 34734	4.54075
$\frac{d^3\alpha}{dt^3}$ for $w = 1$	+ 34820	4.54183
$w = 8$	+ 34729	4.54069
$w = 16$	+ 34737	4.54079

	U^{V} s.	
α for $w = 8$	− 0.000000005893	1.77034*n*
$w = 16$	− 4936	1.69338*n*
$\frac{d\alpha}{dt}$ for $w = 8$	− 5284	1.72296*n*
$w = 16$	− 5184	1.71466*n*
$\frac{d^2\alpha}{dt^2}$ for $w = 1$	− 5083	1.70612*n*
$w = 8$	− 5179	1.71424*n*
$w = 16$	− 5169	1.71341*n*
$\frac{d^3\alpha}{dt^3}$ for $w = 1$	− 5177	1.71408*n*
$w = 8$	− 5181	1.71441*n*
$w = 16$	− 5180	1.71433*n*
$\frac{d^4\alpha}{dt^4}$ for $w = 1$	− 5172	1.71366*n*
$w = 8$	− 5169	1.71341*n*
$w = 16$	− 5169	1.71341*n*

[†] With the coefficient 8, given by Engelmann, the value $+0^s.0000034726$ becomes $+0^s.0000033928$.

U^{VI}

Initial Function.		s.	Logarithms.
a for $w = 8$	−	0.00000000003709	$\bar{9}.56926n$
$w = 16$	−	5725	$\bar{9}.75778n$
$\frac{d\,a}{d\,t}$ for $w = 8$	−	5281	$\bar{9}.72272n$
$w = 16$	−	5652	$\bar{9}.75220n$
$\frac{d^2\,a}{d\,t^2}$ for $w = 1$	−	5556	$\bar{9}.74476n$
$w = 8$	−	5526	$\bar{9}.74241n$
$w = 16$	−	5560	$\bar{9}.74507n$
$\frac{d^3\,a}{d\,t^3}$ for $w = 1$	−	5486	$\bar{9}.73926n$
$w = 8$	−	5551	$\bar{9}.74437n$
$w = 16$	−	5554	$\bar{9}.74461n$
$\frac{d^4\,a}{d\,t^4}$ for $w = 1$	−	5551	$\bar{9}.74437n$
$w = 8$	−	5553	$\bar{9}.74453n$
$w = 16$	−	5554	$\bar{9}.74461n$

U^{VII}

		s.	
a for $w = 8$	+	0.0000000000001892	$\bar{7}.27692$
$w = 16$	+	2548	$\bar{7}.40620$
$\frac{d\,a}{d\,t}$ for $w = 8$	+	1884	$\bar{7}.27509$
$w = 16$	+	3209	$\bar{7}.50637$
$\frac{d^2\,a}{d\,t^2}$ for $w = 8$	+	3178	$\bar{7}.50215$
$w = 16$	+	3105	$\bar{7}.49206$
$\frac{d^3\,a}{d\,t^3}$ for $w = 1$	+	2381	$\bar{7}.37676$
$w = 8$	+	3179	$\bar{7}.50229$
$w = 16$	+	3166	$\bar{7}.50051$
$\frac{d^4\,a}{d\,t^4}$ for $w = 1$	+	3056	$\bar{7}.48515$
$w = 8$	+	3174	$\bar{7}.50161$
$w = 16$	+	3173	$\bar{7}.50147$

U^{VIII}

Initial Function.		s.	Logarithms.
α for $w = 16$	+	0.000000000000000677	$\bar{4}.83059$
$\frac{d\alpha}{dt}$ for $w = 8$	−	1040	$\bar{3}.01703n$
$w = 16$	+	464	$\bar{4}.66652$
$\frac{d^2\alpha}{dt^2}$ for $w = 8$	+	092	$\bar{3}.96379$
$w = 16$	+	207	$\bar{4}.31597$
$\frac{d^3\alpha}{dt^3}$ for $w = 8$	+	150	$\bar{4}.17609$
$w = 16$	+	184	$\bar{4}.26482$
$\frac{d^4\alpha}{dt^4}$ for $w = 1$	+	149	$\bar{4}.17319$
$w = 8$	+	158	$\bar{4}.19866$
$w = 16$	+	163	$\bar{4}.21219$

U^{IX}

		s.	
α for $w = 16$	−	0.00000000000000000277	$\bar{2}.44248n$
$\frac{d\alpha}{dt}$ for $w = 8$	−	2217	$\bar{3}.34576n$
$w = 16$	−	891	$\bar{2}.94988n$
$\frac{d^2\alpha}{dt^2}$ for $w = 8$	−	848	$\bar{2}.92840n$
$w = 16$	−	713	$\bar{2}.85309n$
$\frac{d^3\alpha}{dt^3}$ for $w = 8$	−	896	$\bar{2}.92531n$
$w = 16$	−	805	$\bar{2}.90580n$
$\frac{d^4\alpha}{dt^4}$ for $w = 8$	−	847	$\bar{2}.92788n$
$w = 16$	−	845	$\bar{2}.92686n$

U^{X}

		s.	
α for $w = 16$	−	0.0000000000000000000236	$\bar{0}.37291n$
$\frac{d^2\alpha}{dt^2}$ for $w = 8$	+	450	$\bar{0}.65321$
$w = 16$	+	156	$\bar{0}.19312$
$\frac{d^3\alpha}{dt^3}$ for $w = 8$	+	279	$\bar{0}.44560$
$w = 16$	+	192	$\bar{0}.28330$
$\frac{d^4\alpha}{dt^4}$ for $w = 8$	+	281	$\bar{0}.44871$
$w = 16$	+	259	$\bar{0}.41330$

U^{XI}

Initial Function.		s.	Logarithms.
$\frac{d^3 \alpha}{d t^3}$ for $w = 8$	+	0.0000000000000000000000272	$\bar{\bar{8}}.43457$
$w = 16$	+	63	$\bar{\bar{7}}.79934$
$\frac{d^4 \alpha}{d t^4}$ for $w = 8$	+	125	$\bar{\bar{8}}.09691$
$w = 16$	+	119	$\bar{\bar{8}}.07555$

U^{XII}

		s.	
$\frac{d^4 \alpha}{d t^4}$ for $w = 8$	−	0.000000000000000000000000112	$\bar{\bar{6}}.04922n$
$w = 16$	−	80	$\bar{\bar{5}}.90309n$

It will be advantageous to divide the computation of the terms $U^{I} t \ . \ . \ . \ U^{n} t^{n}$ into two parts.

Representing the sum of the first five terms of the series by Y^4, we have

$$\alpha = \alpha_0 + U^{I} t + U^{II} t^2 + U^{III} t^3 + U^{IV} t^4 = Y_4,$$

in which the terms U^{I}, U^{II}, U^{III}, U^{IV}, are those marked with an asterisk on pp. 260, 261. Y_4 will now remain unchanged, whatever the results for the higher powers of the time.

We shall have, therefore,

$$\alpha = Y_4 + U^{V} t^5 + U^{VI} t^6 + U^{VII} t^7, \text{ \&c.}$$

The computation of the terms $U^{I} t$, $U^{II} t^2$, $U^{III} t^3$, $U^{IV} t^4$, may be advantageously performed by the summation of the series of differences derived from the differential coefficients.

For the instant t_0 we have

$$\Delta_1 = \frac{d\alpha}{dt}, \qquad \Delta_2 = 2 \frac{d^2 \alpha}{d t^2}, \qquad \Delta_3 = 2.3 \frac{d^3 \alpha}{d t^3}, \qquad \Delta_4 = 2.3.4 \frac{d^4 \alpha}{d t^4}, \quad \text{\&c.}$$

For the intervals w, $2w$, $3w$, $4w$, &c., we find:

		Δ_1	Δ_2
For $w = 1$,	$U^{\rm II} t^2 = U^{\rm II} t^2$		
		$U^{\rm II}(2t + 1)$	
$w = 2$,	$U^{\rm II}(t + 1)^2 = U^{\rm II}(t^2 + 2t + 1)$		$2 U^{\rm II}$
		$U^{\rm II}(2t + 3)$	
$w = 3$,	$U^{\rm II}(t + 2)^2 = U^{\rm II}(t^2 + 4t + 4)$		$2 U^{\rm II}$
		$U^{\rm II}(2t + 5)$	
$w = 4$,	$U^{\rm II}(t + 3)^2 = U^{\rm II}(t^2 + 6t + 9)$		

The second differences are therefore constant, and for $w = 1$, $\Delta_2 = \frac{d^2 \alpha}{d t^2}$. For any value of w we have $\Delta_2 = w^2 \frac{d^2 \alpha}{d t^2}$.

In like manner we shall find:

$$\Delta_3 = w^3 \frac{d^3 \alpha}{d t^3}, \qquad \Delta_4 = w^4 \frac{d^4 \alpha}{d t^4}, \qquad \Delta_5 = w^5 \frac{d^5 \alpha}{d t^5}, \qquad \text{\&c.}$$

For the terms following the fourth, it will be better to employ the logarithms of $U^{\rm V}$, $U^{\rm VI}$, &c., in obtaining the products $U^{\rm V} t^5$, $U^{\rm VI} t^6$, &c.

We shall always have the check that for these terms the differences Δ_5, Δ_6, &c., will be constant.

The values of $U^{\rm I} t$ are found by adding the values of $\frac{d \alpha}{d t}$ successively to the initial function.

Having obtained the products $U^{\rm II} t^2$ for three years, of $U^{\rm III} t^3$ for four years, and of $U^{\rm IV} t^4$ for five years, the succeeding terms will be obtained from the differences thereby derived.

The following example will serve as an illustration.

Given

$$U^{\rm II} = -\overset{s.}{0}.1511894 \qquad U^{\rm III} = -\overset{s.}{0}.00033958 \qquad \text{and} \qquad U^{\rm IV} = +\overset{s.}{0}.0000034726$$

we have

	$U^{\rm II} t^2$	Δ_1	Δ_2
	s.		
1876	−0.1511894		
		−0.4535682	
1877	−0.6047576		−0.3023788
		−0.7559470	
1878	−1.3607046		−0.3023788
		−1.0583258	
1879	−2.4190304		−0.3023788
		−1.3607046	
1880	−3.7797350		
	&c.		

	$U^{III} t^3$	Δ_1	Δ_2	Δ_3
	s.			
1876	−0.0003396			
		−0.0023770		
1877	−0.0027166		−0.0040750	
		−0.0064520		−0.0020375
1878	−0.0091686		−0.0061125	
		−0.0125645		−0.0020375
1879	−0.0217331		−0.0081500	
		−0.0207145		−0.0020375
1880	−0.0424476		−0.0101875	
		−0.0309020		
1881	−0.0733496			
	&c.			

	$U^{IV} t^4$	Δ_1	Δ_2	Δ_3	Δ_4
	s.				
1876	+0.0000035				
		+0.0000521			
1877	+0.0000556		+0.0001736		
		+0.0002257		+0.0002084	
1878	+0.0002813		+0.0003820		+0.0000833
		+0.0006077		+0.0002917	
1879	+0.0008890		+0.0006737		+0.0000833
		+0.0012814		+0.0003750	
1880	+0.0021704		+0.0010487		+0.0000833
		+0.0023301		+0.0004583	
1881	+0.0045005		+0.0015070		
		+0.0038371			
1882	+0.0083376				

The following values of Y_4 were obtained in the manner above indicated.

Column 7 contains the values of α derived from equations (6), designated by Y_0.

Column 8 contains the residuals $Y_0 - Y_4$.

REDUCTIONS FROM 1875 TO 1755.

$$1875.0 \quad \alpha_0 = 7^{h}\ 29^{m}\ 5^{s}.6310$$

Date.	$U^{\mathrm{I}}t$			$U^{\mathrm{II}}t^2$		$U^{\mathrm{III}}t^3$		$U^{\mathrm{IV}}t^4$		Y_4			Y_0		Y_0-Y_4
	h.	*m.*	*s.*	*m.*	*s.*	*m.*	*s.*	*m.*	*s.*	*h.*	*m.*	*s.*	*m.*	*s.*	*s.*
1874	−0	1	13.5143	− 0	0.1512	+0	0.0003	+ 0	0.0000	7	27	51.966		....	...
1873	−0	2	27.0286	− 0	0.6048	+0	0.0027	+ 0	0.0001	7	26	38.000		....	...
1872	−0	3	40.5430	− 0	1.3607	+0	0.0092	+ 0	0.0003	7	25	23.737		....	...
1871	−0	4	54.0573	− 0	2.4190	+0	0.0217	+ 0	0.0009	7	24	9.177		....	...
1870	−0	6	7.5716	− 0	3.7797	+0	0.0424	+ 0	0.0022	7	22	54.324		....	...
1869	−0	7	21.0859	− 0	5.4428	+0	0.0733	+ 0	0 0045	7	21	39.180		....	...
1868	−0	8	34.6003	− 0	7.4083	+0	0.1165	+ 0	0.0083	7	20	23.747		....	...
1867	−0	9	48.1146	− 0	9.6761	+0	0.1739	+ 0	0.0142	7	19	8.028	19	8 026	− 0.002
1866	−0	11	1.6289	− 0	12.2463	+0	0.2476	+ 0	0.0228	7	17	52.026		....	...
1865	−0	12	15.1432	− 0	15.1189	+0	0.3396	+ 0	0.0347	7	16	35.743		....	...
1864	−0	13	28.6576	− 0	18.2939	+0	0.4520	+ 0	0 0508	7	15	19 182		....	...
1863	−0	14	42.1719	− 0	21.7713	+0	0.5868	+ 0	0.0720	7	14	2 347		....	...
1862	−0	15	55.6862	− 0	25.5510	+0	0.7460	+ 0	0.0992	7	12	45.239		....	...
1861	−0	17	9.2005	− 0	29.6331	+0	0.9318	+ 0	0.1334	7	11	27.862		....	...
1860	−0	18	22.7149	− 0	34.0176	+0	1.1461	+ 0	0.1758	7	10	10 220		....	...
1859	−0	19	36.2292	− 0	38.7045	+0	1.3909	+ 0	0.2276	7	8	52 316	8	52.315	− 0.001
1858	−0	20	49.7435	− 0	43.6937	+0	1.6683	+ 0	0.2900	7	7	34 152		....	...
1857	−0	22	3.2578	− 0	48.9854	+0	1.9804	+ 0	0.3645	7	6	15.733		....	...
1856	−0	23	16.7722	− 0	54.5794	+0	2.3292	+ 0	0.4526	7	4	57.061		....	...
1855	−0	24	30.2865	− 1	0.4758	+0	2.7166	+ 0	0.5556	7	3	38.141		....	...
1854	−0	25	43.8008	− 1	6.6745	+0	3.1448	+ 0	0.6754	7	2	18.976		....	...
1853	−0	26	57.3151	− 1	13.1757	+0	3.6158	+ 0	0.8135	7	0	59.569		....	...
1852	−0	28	10 8294	− 1	19.9792	+0	4.1316	+ 0	0.9718	6	59	39.926		....	...
1851	−0	29	24.3438	− 1	27.0851	+0	4.6943	+ 0	1.1521	6	58	20.049	58	20.073	+ 0.024
1843	−0	39	12.4584	− 2	34.8180	+0	11.1273	+ 0	3.6413	6	47	33.123	47	33.225	+ 0.102
1835	−0	49	0 5730	− 4	1.9031	+0	21.7329	+ 0	8.8899	6	36	33.778	36	34.034	+ 0 256
1827	−0	58	48.6876	− 5	48.3404	+0	37.5545	+ 0	18.4340	6	25	24.591	25	25 071	+ 0 480
1819	−1	9	36.8022	− 7	54.1299	+0	59.6352	+ 0	34.1513	6	14	8.485	14	9.166	+ 0.681
1811	−1	18	24.9167	−10	19.2719	+1	29.0183	+ 0	58.2606	6	2	48.721	2	49.333	+ 0.612
1803	−1	28	13.0313	−13	3.7660	+2	6.7464	+ 1	33.3222	5	51	28.902	51	28.695	− 0.207
1795	−1	38	1.1459	−16	7.6123	+2	53.8634	+ 2	22.2377	5	40	12 974	40	10.397	− 2.577
1787	−1	47	49.2605	−19	30.8108	+3	51.4123	+ 3	28.2503	5	29	5.222	28	57.519	− 7.703
1779	−1	57	37.3751	−23	13.3616	+5	0.4359	+ 4	54.9440	5	18	10 274	17	52.998	−17.276
1771	−2	7	25.4897	−27	15.2649	+6	21.9782	+ 6	46.2451	5	7	33.100	6	59 542	−33.558
1763	−2	17	13 6043	−31	36.5293	+7	57.0812	+ 9	6.4202	4	57	19.008	56	19.577	−59.431
1755	−2	27	1 7189	−36	17.1276	+9	46.7889	+12	0.0782	4	47	33 652	45	55.203	−98.419

REDUCTIONS FROM 1875 TO 1955.

$$1875.0 \quad \alpha_0 = \overset{h.}{7}\ \overset{m.}{29}\ \overset{s.}{5.6310}$$

Date.	Y_4			Y_0		$Y_0 - Y_4$
	h.	m.	s.	m.	s.	s.
1876	7	30	18.994	....		...
1877	7	31	32.052	....		...
1878	7	32	44.804	....		...
1879	7	33	57.248	....		...
1880	7	35	9.383	....		...
1881	7	36	21.205	....		...
1882	7	37	32.715	....		...
1883	7	38	43.910	38	43.913	+ 0.003
1884	7	39	54.789	....		...
1885	7	41	5.350	....		...
1886	7	42	15.593	....		...
1887	7	43	25.517	....		...
1888	7	44	35.119	....		...
1889	7	45	44.400	....		...
1890	7	46	55.358	....		...
1891	7	48	1.992	48	1.994	+ 0.002
1892	7	49	10.302	....		...
1893	7	50	18.288	....		...
1894	7	51	25.947	....		...
1895	7	52	33.281	....		...
1896	7	53	40.288	....		...
1897	7	54	46.968	....		...
1898	7	55	53.321	....		...
1899	7	56	59.347	56	59.309	− 0.038
1907	8	5	35.785	5	35.579	− 0.206
1915	8	13	51.458	13	50.774	− 0.684
1923	8	21	46.858	21	45.073	− 1.785
1931	8	30	22.819	30	18.828	− 3.991
1939	8	36	40.518	36	32.527	− 7.991
1947	8	43	41.472	43	26.768	−14.704
1955	8	50	27.539	50	2.231	−25.308

Limitations in the Method of Development by Differential Coefficients.

That the method of development by means of differential coefficients expressed in terms of the ascending powers of the time has certain limitations in its application will be evident from an examination of the residuals $Y_0 - Y_4$ given on pages 267 and 268.

The extent of this limitation may be shown in the following manner. Let us assume that an error x occurs in the initial function where its effect will be a maximum. The magnitude of the errors in the successive orders of differences will be represented by the coefficients of x given in the following scheme: —

$$
\begin{array}{ccccccccccccc}
 & \Delta_1 & \Delta_2 & \Delta_3 & \Delta_4 & \Delta_5 & \Delta_6 & \Delta_7 & \Delta_8 & \Delta_9 & \Delta_{10} & \Delta_{11} & \Delta_{12} \\
&&&&&&&&&&&& +x \\
&&&&&&&&&&& +x & \\
&&&&&&&&&& +x && -12x \\
&&&&&&&&& +x && -11x & \\
&&&&&&&& +x && -10x && +66x \\
&&&&&&& +x && -9x && +55x & \\
&&&&&& +x && -8x && +45x && -220x \\
&&&&& +x && -7x && +36x && -165x & \\
&&&& +x && -6x && +28x && -120x && +495x \\
&&& +x && -5x && +21x && -84x && +330x & \\
&& +x && -4x && +15x && -56x && +210x && -792x \\
& +x && -3x && +10x && -35x && +126x && -462x & \\
F(a+x) && -2x && +6x && -20x && +70x && -252x && +924x \\
& -x && +3x && -10x && +35x && -126x && +462x & \\
&& +x && -4x && +15x && -56x && +210x && -792x \\
&&& -x && +5x && -21x && +84x && -330x & \\
&&&& +x && -6x && +28x && -120x && +495x \\
&&&&& -x && +7x && -36x && +165x & \\
&&&&&& +x && -8x && +45x && -220x \\
&&&&&&& -x && +9x && -55x & \\
&&&&&&&& +x && -10x && +66x \\
&&&&&&&&& -x && +11x & \\
&&&&&&&&&& +x && -12x \\
&&&&&&&&&&& -x & \\
&&&&&&&&&&&& +x
\end{array}
\tag{51}
$$

The total effect ϵ of the error x in changing the values of the differential coefficients will be expressed by the equation:

$$
\begin{aligned}
\varepsilon = \quad & \frac{1}{2\,w^2}\Big[-2x - \frac{1}{12}(+6x) + \frac{1}{90}(-20x) - \frac{1}{560}(+70x) + \frac{1}{3150}(-252x) - \ldots \&c.\Big] \\
& \frac{1}{2.3.4\,w^4}\Big[+6x - \frac{1}{6}(-20x) + \frac{7}{240}(+70x) - \frac{41}{7560}(-252x) + \ldots \&c. \\
& \frac{1}{2.3.4.5.6\,w^6}\Big[-20x - \frac{1}{4}(+70x) + \frac{13}{240}(-252x) - \ldots \&c.\Big] \\
& \frac{1}{2.3.4.5.6.7.8\,w^8}\Big[+70x - \frac{1}{3}(-252x) + \ldots \&c.\Big] \\
& \frac{1}{2.3.4.5.6.7.8.9.10\,w^{10}}\Big[-252x - \ldots \&c.\Big] \\
& \frac{1}{2.3.4.5.6.7.8.9.10.11.12\,w^{12}}\Big[+924x + \ldots \&c.\Big]
\end{aligned}
\tag{52}
$$

Simplifying this equation, we have:

$$\varepsilon = -1.46361\frac{x}{w^2} + 0.53090\frac{x}{w^4} - 0.07105\frac{x}{w^6} + 0.0038194\frac{x}{w^8} - 0.00006944\frac{x}{w^{10}} + 0.0000019290\frac{x}{w^{12}} \tag{53}$$

$$= [0.16543n]\frac{x}{w^2} + [9.72501]\frac{x}{w^4} + [8.85156n]\frac{x}{w^6} + [7.58200]\frac{x}{w^8} + [5.84164n]\frac{x}{w^{10}} + [4.28534]\frac{x}{w^{12}}.$$

From equation (53) we derive the following numerical values of the effect of the error x for $w=1$, $w=8$, $w=16$, $w=30$, and $w=40$:

	$w=1$	$w=1$	$w=8$	$w=8$
		Logarithms.		Logarithms.
U^{II}	$-1.4636x$	$[0.16543n]x$	$-0.022869x$	$[8.35925n]x$
U^{IV}	$+0.53090x$	$[9.72501]x$	$+0.00012961x$	$[6.11264]x$
U^{VI}	$-0.071049x$	$[8.85156n]x$	$-0.00000027103x$	$[3.43302n]x$
U^{VIII}	....	....	$+0.00000000022766x$	$[0.35729]x$
U^{X}	....	....	$-0.00000000000000064676x$	$[\bar{6}.81074n]x$
U^{XII}	....	....	$+0.00000000000000000028071x$	$[\bar{3}.44826]x$

	$w=16$	$w=16$	$w=30$	$w=40$
		Logarithms.	Logarithms.	Logarithms.
U^{II}	$-0.0057173x$	$[7.75719n]x$	$[7.21119n]x$	$[6.96131n]x$
U^{IV}	$+0.0000081009x$	$[4.90853]x$	$[3.81653]x$	$[3.31677]x$
U^{VI}	$-0.0000000042349x$	$[1.62684n]x$	$[\bar{9}.98883n]x$	$[\bar{9}.23920n]x$
U^{VIII}	$+0.0000000000000088929x$	$[\bar{7}.94904]x$	$[\bar{5}.76503]x$	$[\bar{4}.76552]x$
U^{X}	$-0.0000000000000000063160x$	$[\bar{3}.80044n]x$	$[\bar{1}.07043n]x$	$[\bar{\bar{9}}.82104n]x$
U^{XII}	$+0.0000000000000000000068534x$	$[\bar{\bar{9}}.83591]x$	$[\bar{\bar{6}}.55989]x$	$[\bar{\bar{5}}.06062]x$

We illustrate the computation by assuming

x = one unit in the third decimal place of α for 1875.0.

Then, assuming

$t = 10$ for $w = 1$
$t = 40$ for $w = 8$
$t = 40$ for $w = 16$
$t = 100$ for $w = 16$
$t = 120$ for $w = 16$
$t = 120$ for $w = 30$
$t = 120$ for $w = 40$

we have for the total effect ϵ of the error x:

	$w = 1$ $t = 10$	$w = 8$ $t = 40$	$w = 16$ $t = 40$	$w = 16$ $t = 100$	$w = 16$ $t = 120$	$w = 30$ $t = 120$	$w = 40$ $t = 120$
	s.	s.	s.	s.	s.	s.	s.
$U^{II}t^2$	− 0.146	−0.037	−0.009	−0.057	− 0.082	−0.023	−0.013
$U^{IV}t^4$	+ 5.309	+0.332	+0.021	+0.810	+ 1.680	+0.136	+0.043
$U^{VI}t^6$	−71.049	−1.110	−0.017	−4.235	−12.645	−0.291	−0.052
$U^{VIII}t^8$	. . . .	+1.492	+0.006	+8.893	+38.238	+0.250	+0.025
$U^{X}t^{10}$	. . . .	−0.678	−0.001	−6.316	−39.107	−0.073	−0.004
$U^{XII}t^{12}$	. . . .	+0.471	+0.000	+6.853	+61.106	+0.032	+0.001
Sums		+0.470	+0.000	+5.948	+49.190	+0.031	+0.000

The decided advantage in the choice of a large value for the interval *w* is very obvious from these results. It is, however, important to be remembered that these values of ϵ are the result of a single error producing a maximum effect. The errors which occur ordinarily in the use of logarithmic tables are likely to be distributed with considerable regularity, and these errors will probably neutralize each other to some extent.

TABULAR VALUES OF THE LOGARITHMS OF THE FIFTH AND HIGHER POWERS OF THE TIME FROM 8 TO 120 YEARS.

t	log t^5	log t^6	log t^7	log t^8	log t^9	log t^{10}	log t^{11}	log t^{12}
8	4.51545	5.41854	6.32163	7.22472	8.12781	9.03090	9.93399	10.83708
9	4.77121	5.72545	6.67970	7.63394	8.58818	9.54242	10.49667	11.45091
10	5.00000	6.00000	7.00000	8.00000	9.00000	10.00000	11.00000	12.00000
11	5.20696	6.24836	7.28975	8.33114	9.37253	10.41393	11.45532	12.49671
12	5.39591	6.47509	7.55427	8.63345	9.71263	10.79182	11.87099	12.95017
13	5.56972	6.68366	7.79760	8.91155	10.02549	11.13943	12.25338	13.36732
14	5.73064	6.87677	8.02290	9.16902	10.31515	11.46128	12.60741	13.75354
15	5.88046	7.05655	8.23264	9.40873	10.58482	11.76091	12.93700	14.11310
16	6.02060	7.22472	8.42884	9.63296	10.83708	12.04120	13.24532	14.44944
17	6.15224	7.38269	8.61314	9.84359	11.07404	12.30449	13.53494	14.76539
18	6.27636	7.53164	8.78691	10.04218	11.29745	12.55272	13.80800	15.06327
19	6.39377	7.67252	8.95128	10.23003	11.50878	12.78754	14.06629	15.34504
20	6.50515	7.80618	9.10721	10.40824	11.70927	13.01030	14.31133	15.61236
21	6.61110	7.93332	9.25553	10.57775	11.89997	13.22219	14.54441	15.86663
22	6.71211	8.05454	9.39696	10.73938	12.08180	13.42423	14.76665	16.10907
23	6.80864	8.17037	9.53209	10.89382	12.25555	13.61728	14.97901	16.34073
24	6.90106	8.28127	9.66148	11.04169	12.42190	13.80211	15.18232	16.56253
32	7.52575	9.03090	10.53605	12.04120	13.54635	15.05150	16.55665	18.06180
40	8.01030	9.61236	11.21442	12.81648	14.41854	16.02060	17.62266	19.22472
48	8.40621	10.08745	11.76869	13.44993	15.13117	16.81241	18.49365	20.17489
56	8.74094	10.48913	12.23732	13.98550	15.73369	17.48188	19.23007	20.97826
64	9.03090	10.83708	12.64326	14.44944	16.25562	18.06180	19.86798	21.67416
72	9.28666	11.14399	13.00133	14.85866	16.71599	18.57332	20.43066	22.28799
80	9.51545	11.41854	13.32163	15.22472	17.12781	19.03090	20.93399	22.83708
88	9.72241	11.66690	13.61138	15.55586	17.50034	19.44483	21.38931	23.33379
96	9.91136	11.89363	13.87590	15.85817	17.84044	19.82271	21.80498	23.78725
104	10.08517	12.10220	14.11923	16.13627	18.15330	20.17033	22.18737	24.20440
112	10.24609	12.29531	14.34453	16.39374	18.44296	20.49218	22.54140	24.59062
120	10.39591	12.47509	14.55427	16.63345	18.71263	20.79181	22.87099	24.95017

By the aid of this table the following values of $U^{\text{V}} t^5 \dots U^{\text{XII}} t^{12}$ were computed with the values of $U^{\text{V}} \dots U^{\text{XII}}$ given on pp. 261–264.

Representing the initial function by J we have:

$U^{\text{V}} t^5$.

Epoch.		$J = \alpha$	$J = \frac{d\,\alpha}{d\,t}$	$J = \frac{d^2\,\alpha}{d\,t^2}$	$J = \frac{d^3\,\alpha}{d\,t^3}$	$J = \frac{d^4\,\alpha}{d\,t^4}$
		s.	s.	s.	s.	s.
1851	$w =$ 1	. . . .	. . . .	+ 0.041	+ 0.041	+ 0.041
	8	+ 0.047	+ 0.042	+ 0.040	+ 0.041	+ 0.041
	16	+ 0.039	+ 0.041	+ 0.041	+ 0.041	+ 0.041
1843	$w =$ 1	. . . .	. . . .	+ 0.170	+ 0.174	+ 0.174
	8	+ 0.198	+ 0.177	+ 0.174	+ 0.174	+ 0.173
	16	+ 0.166	+ 0.174	+ 0.173	+ 0.174	+ 0.173
1835	$w =$ 1	. . . .	. . . .	+ 0.521	+ 0.530	+ 0.530
	8	+ 0.603	+ 0.541	+ 0.530	+ 0.530	+ 0.529
	16	+ 0.505	+ 0.531	+ 0.529	+ 0.530	+ 0.529
1827	$w =$ 1	. . . .	. . . .	+ 1.295	+ 1.319	+ 1.318
	8	+ 1.502	+ 1.346	+ 1.320	+ 1.320	+ 1.317
	16	+ 1.258	+ 1.321	+ 1.317	+ 1.320	+ 1.317
1819	$w =$ 1	. . . .	. . . .	+ 2.799	+ 2.851	+ 2.848
	8	+ 3.245	+ 2.910	+ 2.852	+ 2.853	+ 2.847
	16	+ 2.718	+ 2.855	+ 2.847	+ 2.853	+ 2.847
1811	$w =$ 1	. . . .	. . . .	+ 5.458	+ 5.559	+ 5.553
	8	+ 6.328	+ 5.674	+ 5.561	+ 5.563	+ 5.550
	16	+ 5.300	+ 5.566	+ 5.550	+ 5.562	+ 5.550
1803	$w =$ 1	. . . .	. . . .	+ 9.835	+ 10.017	+ 10.007
	8	+ 11.403	+ 10.224	+ 10.021	+ 10.025	+ 10.002
	16	+ 9.551	+ 10.030	+ 10.002	+ 10.023	+ 10.002
1795	$w =$ 1	. . . .	. . . .	+ 16.656	+ 16.964	+ 16.948
	8	+ 19.310	+ 17.315	+ 16.970	+ 16.977	+ 16.938
	16	+ 16.174	+ 16.987	+ 16.938	+ 16.974	+ 16.938
1787	$w =$ 1	. . . .	. . . .	+ 26.824	+ 27.321	+ 27.294
	8	+ 31.099	+ 27.885	+ 27.331	+ 27.341	+ 27.278
	16	+ 26.049	+ 27.357	+ 27.278	+ 27.336	+ 27.278
1779	$w =$ 1	. . . .	. . . .	+ 41.446	+ 42.212	+ 42.172
	8	+ 48.051	+ 43.085	+ 42.228	+ 42.244	+ 42.147
	16	+ 40.248	+ 42.269	+ 42.147	+ 42.237	+ 42.147
1771	$w =$ 1	. . . .	. . . .	+ 61.843	+ 62.987	+ 62.926
	8	+ 71.699	+ 64.288	+ 63.011	+ 63.035	+ 62.890
	16	+ 60.056	+ 63.071	+ 62.890	+ 63.024	+ 62.890
1763	$w =$ 1	. . . .	. . . .	+ 89.580	+ 91.237	+ 91.148
	8	+103.858	+ 93.122	+ 91.271	+ 91.307	+ 91.097
	16	+ 86.990	+ 91.359	+ 91.097	+ 91.289	+ 91.097
1755	$w =$ 1	. . . .	. . . .	+126.483	+128.820	+128.698
	8	+146.639	+131.485	+128.870	+128.920	+128.623
	16	+122.826	+128.994	+128.623	+128.896	+128.623

$U^{VI} t^6$.

Epoch.		$J = \alpha$	$J = \frac{d\alpha}{dt}$	$J = \frac{d^2\alpha}{dt^2}$	$J = \frac{d^3\alpha}{dt^3}$	$J = \frac{d^4\alpha}{dt^4}$
		s.	s.	s.	s.	s.
1851	$w =$ 1	. . . .	. . . .	− 0.011	− 0.010	− 0.011
	8	− 0.007	− 0.010	− 0.011	− 0.011	− 0.011
	16	− 0.011	− 0.011	− 0.011	− 0.011	− 0.011
1843	$w =$ 1	. . . .	. . . .	− 0.060	− 0.059	− 0.060
	8	− 0.040	− 0.057	− 0.059	− 0.060	− 0.060
	16	− 0.061	− 0.061	− 0.060	− 0.060	− 0.060
1835	$w =$ 1	. . . .	. . . .	− 0.228	− 0.225	− 0.227
	8	− 0.152	− 0.216	− 0.226	− 0.227	− 0.227
	16	− 0.234	− 0.232	− 0.228	− 0.228	− 0.228
1827	$w =$ 1	. . . .	. . . .	− 0.680	− 0.671	− 0.679
	8	− 0.454	− 0.646	− 0.676	− 0.679	− 0.679
	16	− 0.700	− 0.691	− 0.680	− 0.682	− 0.682
1819	$w =$ 1	. . . .	. . . .	− 1.714	− 1.692	− 1.712
	8	− 1.144	− 1.629	− 1.704	− 1.712	− 1.713
	16	− 1.766	− 1.743	− 1.715	− 1.713	− 1.713
1811	$w =$ 1	. . . .	. . . .	− 3.818	− 3.770	− 3.815
	8	− 2.549	− 3.629	− 3.797	− 3.815	− 3.816
	16	− 3.934	− 3.884	− 3.821	− 3.817	− 3.817
1803	$w =$ 1	. . . .	. . . .	− 7.740	− 7.643	− 7.733
	8	− 5.167	− 7.357	− 7.698	− 7.733	− 7.736
	16	− 7.976	− 7.874	− 7.746	− 7.738	− 7.738
1795	$w =$ 1	. . . .	. . . .	− 14.565	− 14.381	− 14.552
	8	− 9.723	− 13.844	− 14.486	− 14.552	− 14.557
	16	− 15.008	− 14.816	− 14.575	− 14.560	− 14.560
1787	$w =$ 1	. . . .	. . . .	− 25.802	− 25.478	− 25.779
	8	− 17.225	− 24.526	− 25.663	− 27.779	− 25.789
	16	− 26.588	− 26.248	− 25.821	− 25.794	− 25.794
1779	$w =$ 1	. . . .	. . . .	− 43.490	− 42.943	− 43.451
	8	− 29.033	− 41.338	− 43.255	− 43.451	− 43.467
	16	− 44.814	− 44.242	− 43.521	− 43.475	− 43.475
1771	$w =$ 1	. . . .	. . . .	− 70.301	− 69.416	− 70.238
	8	− 46.931	− 66.822	− 69.922	− 70.238	− 70.265
	16	− 72.441	− 71.516	− 70.351	− 70.277	− 70.277
1763	$w =$ 1	. . . .	. . . .	−109.667	−108.285	−109.567
	8	− 73.210	−104.240	−109.076	−109.567	−109.607
	16	−113.002	−111.560	−109.746	−109.628	−109.628
1755	$w =$ 1	. . . .	. . . .	−165.900	−163.814	−165.753
	8	−110.752	−157.693	−165.007	−165.753	−165.814
	16	−170.950	−168.768	−166.020	−165.844	−165.844

$U^{\mathrm{VII}}\, t^7$.

Epoch.		$J = \alpha$	$J = \frac{d\,\alpha}{d\,t}$	$J = \frac{d^2\,\alpha}{d\,t^2}$	$J = \frac{d^3\,\alpha}{d\,t^3}$	$J = \frac{d^4\,\alpha}{d\,t^4}$
		s.	s.	s.	s.	s.
1851	$w =$ 1	. . . .	. . . .	. . . .	− 0.001	− 0.001
	8	− 0.001	− 0.001	− 0.001	− 0.001	− 0.001
	16	− 0.001	− 0.001	− 0.001	− 0.001	− 0.001
1843	$w =$ 1	. . . .	. . . .	. . . .	− 0.008	− 0.010
	8	− 0.006	− 0.006	− 0.011	− 0.011	− 0.011
	16	− 0.009	− 0.011	− 0.011	− 0.011	− 0.011
1835	$w =$ 1	. . . .	. . . .	. . . .	− 0.039	− 0.050
	8	− 0.031	− 0.031	− 0.052	− 0.052	− 0.052
	16	− 0.042	− 0.053	− 0.051	− 0.052	− 0.052
1827	$w =$ 1	. . . .	. . . .	. . . .	− 0.140	− 0.179
	8	− 0.111	− 0.111	− 0.187	− 0.187	− 0.186
	16	− 0.150	− 0.188	− 0.182	− 0.186	− 0.186
1819	$w =$ 1	. . . .	. . . .	. . . .	− 0.411	− 0.528
	8	− 0.327	− 0.325	− 0.549	− 0.549	− 0.548
	16	− 0.440	− 0.554	− 0.536	− 0.547	− 0.548
1811	$w =$ 1	. . . .	. . . .	. . . .	− 1.047	− 1.344
	8	− 0.832	− 0.829	− 1.398	− 1.398	− 1.396
	16	− 1.121	− 1.411	− 1.366	− 1.392	− 1.396
1803	$w =$ 1	. . . .	. . . .	. . . .	− 2.388	− 3.065
	8	− 1.898	− 1.890	− 3.188	− 3.189	− 3.184
	16	− 2.556	− 3.219	− 3.114	− 3.176	− 3.183
1795	$w =$ 1	. . . .	. . . .	. . . .	− 4.993	− 6.409
	8	− 3.968	− 3.951	− 6.665	− 6.667	− 6.656
	16	− 5.343	− 6.730	− 6.512	− 6.639	− 6.654
1787	$w =$ 1	. . . .	. . . .	. . . .	− 9.731	− 12.489
	8	− 7.732	− 7.700	− 12.988	− 12.992	− 12.972
	16	− 10.413	− 13.114	− 12.689	− 12.939	− 12.967
1779	$w =$ 1	. . . .	. . . .	. . . .	− 17.892	− 22.964
	8	− 14.217	− 14.158	− 23.881	− 23.889	− 23.851
	16	− 19.147	− 24.114	− 23.333	− 23.791	− 23.844
1771	$w =$ 1	. . . .	. . . .	. . . .	− 31.332	− 40.214
	8	− 24.897	− 24.793	− 41.820	− 41.833	− 41.768
	16	− 33.530	− 42.228	− 40.860	− 41.662	− 41.754
1763	$w =$ 1	. . . .	. . . .	. . . .	− 52.637	− 67.558
	8	− 41.827	− 41.651	− 70.256	− 70.278	− 70.168
	16	− 56.329	− 70.942	− 68.642	− 69.991	− 70.146
1755	$w =$ 1	. . . .	. . . .	. . . .	− 85.316	−109.502
	8	− 67.794	− 67.508	−113.873	−113.909	−113.732
	16	− 91.300	−114.984	−111.258	−113.444	−113.695

$U^{\mathrm{VIII}}\, t^8$.

Epoch.		$J = \alpha$	$J = \frac{d\alpha}{dt}$	$J = \frac{d^2\alpha}{dt^2}$	$J = \frac{d^3\alpha}{dt^3}$	$J = \frac{d^4\alpha}{dt^4}$
		s.	s.	s.	s.	s.
1851	$w =$ 1	....	....	....	....	+ 0.000
	8	....	− 0.000	+ 0.000	+ 0.000	+ 0.000
	16	+ 0.000	+ 0.000	+ 0.000	+ 0.000	+ 0.000
1843	$w =$ 1	....	....	....	....	+ 0.000
	8	....	− 0.001	+ 0.000	+ 0.000	+ 0.000
	16	+ 0.001	+ 0.000	+ 0.000	+ 0.000	+ 0.000
1835	$w =$ 1	....	....	....	....	+ 0.001
	8	....	− 0.007	+ 0.001	+ 0.001	+ 0.001
	16	+ 0.004	+ 0.003	+ 0.001	+ 0.001	+ 0.001
1827	$w =$ 1	....	....	....	....	+ 0.004
	8	....	− 0.029	+ 0.003	+ 0.004	+ 0.004
	16	+ 0.019	+ 0.013	+ 0.006	+ 0.005	+ 0.005
1819	$w =$ 1	....	....	....	....	+ 0.014
	8	....	− 0.101	+ 0.009	+ 0.014	+ 0.015
	16	+ 0.065	+ 0.045	+ 0.020	+ 0.018	+ 0.016
1811	$w =$ 1	....	....	....	....	+ 0.042
	8	....	− 0.293	+ 0.026	+ 0.042	+ 0.044
	16	+ 0.191	+ 0.131	+ 0.058	+ 0.052	+ 0.046
1803	$w =$ 1	....	....	....	....	+ 0.108
	8	....	− 0.751	+ 0.066	+ 0.108	+ 0.114
	16	+ 0.489	+ 0.335	+ 0.150	+ 0.133	+ 0.118
1795	$w =$ 1	....	....	....	....	+ 0.250
	8	....	− 1.744	+ 0.154	+ 0.252	+ 0.265
	16	+ 1.136	+ 0.778	+ 0.347	+ 0.309	+ 0.274
1787	$w =$ 1	....	....	....	....	+ 0.536
	8	....	− 3.740	+ 0.331	+ 0.539	+ 0.568
	16	+ 2.435	+ 1.669	+ 0.744	+ 0.662	+ 0.586
1779	$w =$ 1	....	....	....	....	+ 1.075
	8	....	− 7.502	+ 0.664	+ 1.082	+ 1.140
	16	+ 4.884	+ 3.347	+ 1.493	+ 1.327	+ 1.176
1771	$w =$ 1	....	....	....	....	+ 2.039
	8	....	− 14.233	+ 1.259	+ 2.053	+ 2.162
	16	+ 9.265	+ 6.350	+ 2.833	+ 2.518	+ 2.231
1763	$w =$ 1	....	....	....	....	+ 3.689
	8	....	− 25.750	+ 2.278	+ 3.714	+ 3.912
	16	+ 16.762	+ 11.488	+ 5.125	+ 4.556	+ 4.036
1755	$w =$ 1	....	....	....	....	+ 6.407
	8	....	− 44.718	+ 3.956	+ 6.450	+ 6.794
	16	+ 29.110	+ 19.951	+ 8.901	+ 7.912	+ 7.009

$U^{\text{IX}} t^{9}$.

Epoch.		$J=\alpha$	$J=\frac{d\alpha}{dt}$	$J=\frac{d^2\alpha}{dt^2}$	$J=\frac{d^3\alpha}{dt^3}$	$J=\frac{d^4\alpha}{dt^4}$
		s.	s.	s.	s.	s.
1851	$w=$ 8	....	+ 0.000	+ 0.000	+ 0.000	+ 0.000
	16	+ 0.000	+ 0.000	+ 0.000	+ 0.000	+ 0.000
1843	$w=$ 8	....	+ 0.001	+ 0.000	+ 0.000	+ 0.000
	16	+ 0.000	+ 0.000	+ 0.000	+ 0.000	+ 0.000
1835	$w=$ 8	....	+ 0.006	+ 0.002	+ 0.002	+ 0.002
	16	+ 0.001	+ 0.002	+ 0.002	+ 0.002	+ 0.002
1827	$w=$ 8	....	+ 0.030	+ 0.012	+ 0.011	+ 0.011
	16	+ 0.004	+ 0.012	+ 0.010	+ 0.011	+ 0.011
1819	$w=$ 8	....	+ 0.120	+ 0.046	+ 0.046	+ 0.048
	16	+ 0.015	+ 0.048	+ 0.039	+ 0.044	+ 0.046
1811	$w=$ 8	....	+ 0.399	+ 0.153	+ 0.152	+ 0.153
	16	+ 0.050	+ 0.160	+ 0.128	+ 0.145	+ 0.152
1803	$w=$ 8	....	+ 1.153	+ 0.440	+ 0.438	+ 0.440
	16	+ 0.144	+ 0.463	+ 0.371	+ 0.419	+ 0.439
1795	$w=$ 8	....	+ 2.976	+ 1.138	+ 1.130	+ 1.137
	16	+ 0.372	+ 1.196	+ 0.957	+ 1.080	+ 1.134
1787	$w=$ 8	....	+ 7.016	+ 2.684	+ 2.665	+ 2.680
	16	+ 0.877	+ 2.820	+ 2.257	+ 2.548	+ 2.674
1779	$w=$ 8	....	+15.354	+ 5.873	+ 5.831	+ 5.866
	16	+ 1.918	+ 6.170	+ 4.938	+ 5.575	+ 5.852
1771	$w=$ 8	....	+31.555	+12.070	+11.984	+12.055
	16	+ 3.943	+12.682	+10.148	+11.457	+12.027
1763	$w=$ 8	....	+61.479	+23.516	+23.349	+23.488
	16	+ 7.681	+24.708	+19.772	+22.323	+23.433
1755	$w=$ 8	....	+114.391	+43.755	+43.445	+43.703
	16	+14.293	+45.974	+36.789	+41.537	+43.600

$U^{X}\, t^{10}$.

Epoch.		$J = \alpha$	$J = \frac{d^2 \alpha}{d t^2}$	$J = \frac{d^3 \alpha}{d t^3}$	$J = \frac{d^4 \alpha}{d t^4}$
		s.	s.	s.	s.
1851	$w =$ 8	. . . .	+ 0.000	+ 0.000	+ 0.000
	16	− 0.000	+ 0.000	+ 0.000	+ 0.000
1843	$w =$ 8	. . . .	+ 0.000	+ 0.000	+ 0.000
	16	− 0.000	+ 0.000	+ 0.000	+ 0.000
1835	$w =$ 8	. . . .	+ 0.000	+ 0.000	+ 0.000
	16	− 0.000	+ 0.000	+ 0.000	+ 0.000
1827	$w =$ 8	. . . .	+ 0.003	+ 0.002	+ 0.002
	16	− 0.002	+ 0.001	+ 0.001	+ 0.002
1819	$w =$ 8	. . . .	+ 0.014	+ 0.008	+ 0.008
	16	− 0.007	+ 0.005	+ 0.006	+ 0.008
1811	$w =$ 8	. . . .	+ 0.052	+ 0.032	+ 0.032
	16	− 0.027	+ 0.018	+ 0.022	+ 0.030
1803	$w =$ 8	. . . .	+ 0.168	+ 0.104	+ 0.105
	16	− 0.088	+ 0.058	+ 0.072	+ 0.097
1795	$w =$ 8	. . . .	+ 0.483	+ 0.300	+ 0.302
	16	− 0.253	+ 0.168	+ 0.206	+ 0.278
1787	$w =$ 8	. . . .	+ 1.253	+ 0.777	+ 0.783
	16	− 0.657	+ 0.434	+ 0.535	+ 0.721
1779	$w =$ 8	. . . .	+ 2.992	+ 1.855	+ 1.868
	16	− 1.569	+ 1.037	+ 1.276	+ 1.722
1771	$w =$ 8	. . . .	+ 6.661	+ 4.130	+ 4.159
	16	− 3.493	+ 2.309	+ 2.842	+ 3.834
1763	$w =$ 8	. . . .	+13.976	+ 8.665	+ 8.727
	16	− 7.330	+ 4.845	+ 5.963	+ 8.044
1755	$w =$ 8	. . . .	+27.863	+17.275	+17.399
	16	−14.613	+ 9.659	+11.888	+16.037

Epoch.		$U^{XI}\,t^{11}$.		$U^{XII}\,t^{12}$.
		$J = \frac{d^3 a}{d\,t^3}$	$J = \frac{d^4 a}{d\,t^4}$	$J = \frac{d^4 a}{d\,t^4}$
		s.	s.	s.
1851	$w =$ 8	− 0.000	− 0.000	− 0.000
	16	− 0.000	− 0.000	− 0.000
1843	$w =$ 8	− 0.000	− 0.000	− 0.000
	16	− 0.000	− 0.000	− 0.000
1835	$w =$ 8	− 0.000	− 0.000	− 0.000
	16	− 0.000	− 0.000	− 0.000
1827	$w =$ 8	− 0.001	− 0.000	− 0.000
	16	− 0.000	− 0.000	− 0.000
1819	$w =$ 8	− 0.005	− 0.002	− 0.001
	16	− 0.001	− 0.002	− 0.001
1811	$w =$ 8	− 0.020	− 0.009	− 0.005
	16	− 0.005	− 0.009	− 0.004
1803	$w =$ 8	− 0.073	− 0.034	− 0.022
	16	− 0.017	− 0.032	− 0.016
1795	$w =$ 8	− 0.234	− 0.107	− 0.077
	16	− 0.054	− 0.102	− 0.055
1787	$w =$ 8	− 0.667	− 0.306	− 0.242
	16	− 0.154	− 0.292	− 0.172
1779	$w =$ 8	− 1.736	− 0.798	− 0.686
	16	− 0.402	− 0.760	− 0.490
1771	$w =$ 8	− 4.187	− 1.924	− 1.793
	16	− 0.970	− 1.832	− 1.281
1763	$w =$ 8	− 9.462	− 4.348	− 4.364
	16	− 2.192	− 4.140	− 3.117
1755	$w =$ 8	− 20.210	− 9.287	− 9.986
	16	− 4.681	− 8.842	− 7.133

Sum of the Terms $U^{V} t^{5} + U^{VI} t^{6} + U^{VII} t^{7} + \&c. \ldots U^{XII} t^{12}$.

Designating the sum of the terms, from the fifth forward, by the number of the last term, we have:

Epoch.	$t - 1875$.		$J = \alpha$	$J = \frac{d\alpha}{dt}$	$J = \frac{d^2\alpha}{dt^2}$	$J = \frac{d^3\alpha}{dt^3}$	$J = \frac{d^4\alpha}{dt^4}$
			s.	s.	s.	s.	s.
1851	− 24	$w =$ 1	. . . .	. . . .	VI + 0.030	VII + 0.030	VIII + 0.029
		8	VII + 0.039	IX + 0.031	X + 0.028	XI + 0.029	XII + 0.029
		16	X + 0.027	IX + 0.029	X + 0.029	XI + 0.029	XII + 0.029
1843	− 32	$w =$ 1	. . . .	. . . .	VI + 0.111	VII + 0.107	VIII + 0.104
		8	VII + 0.152	IX + 0.114	X + 0.104	XI + 0.103	XII + 0.102
		16	X + 0.097	IX + 0.102	X + 0.102	XI + 0.103	XII + 0.102
1835	− 40	$w =$ 1	. . . .	. . . .	VI + 0.293	VII + 0.266	VIII + 0.254
		8	VII + 0.420	IX + 0.293	X + 0.255	XI + 0.254	XII + 0.253
		16	X + 0.234	IX + 0.251	X + 0.253	XI + 0.253	XII + 0.252
1827	− 48	$w =$ 1	. . . .	. . . .	VI + 0.615	VII + 0.508	VIII + 0.464
		8	VII + 0.937	IX + 0.590	X + 0.475	XI + 0.470	XII + 0.469
		16	X + 0.429	IX + 0.467	X + 0.472	XI + 0.469	XII + 0.467
1819	− 56	$w =$ 1	. . . .	. . . .	VI + 1.085	VII + 0.748	VIII + 0.622
		8	VII + 1.774	IX + 0.975	X + 0.668	XI + 0.655	XII + 0.654
		16	X + 0.585	IX + 0.651	X + 0.660	XI + 0.660	XII + 0.653
1811	− 64	$w =$ 1	. . . .	. . . .	VI + 1.640	VII + 0.742	VIII + 0.436
		8	VII + 2.947	IX + 1.322	X + 0.597	XI + 0.556	XII + 0.553
		16	X + 0.459	IX + 0.562	X + 0.567	XI + 0.567	XII + 0.552
1803	− 72	$w =$ 1	. . . .	. . . .	VI + 2 095	VII − 0.014	VIII − 0.683
		8	VII + 4.338	IX + 1.379	X − 0.191	XI − 0.320	XII − 0.315
		16	X − 0.436	IX − 0.265	X − 0.279	XI − 0.284	XII − 0.313
1795	− 80	$w =$ 1	. . . .	. . . .	VI + 2.091	VII − 2.410	VIII − 3.763
		8	VII + 5.619	IX + 0.752	X − 2.406	XI − 2.794	XII − 2.755
		16	X − 2.922	IX − 2.585	X − 2.677	XI − 2.684	XII − 2.747
1787	− 88	$w =$ 1	. . . .	. . . .	VI + 1.022	VII − 7.888	VIII − 10.438
		8	VII + 6.142	IX − 1.065	X − 7.052	XI − 8.116	XII − 8 000
		16	X − 8.297	IX − 7.516	X − 7.797	XI − 7.806	XII − 7.966
1779	− 96	$w =$ 1	. . . .	. . . .	VI − 2.044	VII − 18.623	VIII − 23.168
		8	VII + 4.801	IX − 4.559	X − 15.379	XI − 18.064	XII − 17.781
		16	X − 18.480	IX − 16.570	X − 17.239	XI − 17.253	XII − 17.672
1771	− 104	$w =$ 1	. . . .	. . . .	VI − 8.458	VII − 37.761	VIII − 45.487
		8	VII − 0.129	IX − 10.005	X − 28.741	XI − 35.056	XII − 34.484
		16	X − 36.200	IX − 31.641	X − 33.031	XI − 33.068	XII − 34.162
1763	− 112	$w =$ 1	. . . .	. . . .	VI − 20.087	VII − 69.685	VIII − 82 288
		8	VII − 11.179	IX − 17.040	X − 48.291	XI − 62.272	XII − 61.263
		16	X − 65.228	IX − 54.947	X − 57.549	XI − 57.680	XII − 60.421
1755	− 120	$w =$ 1	. . . .	. . . .	VI − 39.417	VII − 120.310	VIII − 140.150
		8	VII − 31.907	IX − 24.043	X − 74.436	XI − 103.782	XII − 102.300
		16	X − 110.634	IX − 88.833	X − 93.306	XI − 93.736	XII − 100.245

Sums of Y_4 and succeeding Terms.

Designating the sums of the terms of the entire series by the number of the last term, we have:

Epoch.			$J = \alpha$	$J = \frac{d\,\alpha}{d\,t}$	$J = \frac{d^2\,\alpha}{d\,t^2}$	$J = \frac{d^3\,\alpha}{d\,t^3}$	$J = \frac{d^4\,\alpha}{d\,t^4}$
	h. m. s.		m. s.	m. s.	m. s.	m. s.	m. s.
1851	Y_4 6 58 20.048	$w = 1$	... .	... .	Y_6 58 20.078	Y_7 58 20.078	Y_8 58 20.077
	Y_0 6 58 20.073	8	Y_7 58 20.087	Y_9 58 20.079	Y_{10} 58 20.076	Y_{11} 58 20.077	Y_{12} 58 20.077
		16	Y_{10} 58 20.075	Y_9 58 20.077	Y_{10} 58 20.077	Y_{11} 58 20.077	Y_{12} 58 20.077
1843	Y_4 6 47 33.123	$w = 1$	... .	... .	Y_6 47 33.234	Y_7 47 33.230	Y_8 47 33.227
	Y_0 6 47 33.225	8	Y_7 47 33.275	Y_9 47 33.237	Y_{10} 47 33.227	Y_{11} 47 33.226	Y_{12} 47 33.225
		16	Y_{10} 47 33.220	Y_9 47 33.225	Y_{10} 47 33.225	Y_{11} 47 33.226	Y_{12} 47 33.225
1835	Y_4 6 36 33.778	$w = 1$	... .	... .	Y_6 36 34.071	Y_7 36 34.044	Y_8 36 34.032
	Y_0 6 36 34.034	8	Y_7 36 34.198	Y_9 36 34.071	Y_{10} 36 34.033	Y_{11} 36 34.032	Y_{12} 36 34.031
		16	Y_{10} 36 34.012	Y_9 36 34.029	Y_{10} 36 34.031	Y_{11} 36 34.031	Y_{12} 36 34.030
1827	Y_4 6 25 24.592	$w = 1$	... .	... .	Y_6 25 25.207	Y_7 25 25.100	Y_8 25 25.056
	Y_0 6 25 25.071	8	Y_7 25 25.529	Y_9 25 25.182	Y_{10} 25 25.067	Y_{11} 25 25.062	Y_{12} 25 25.061
		16	Y_{10} 25 25.021	Y_9 25 25.059	Y_{10} 25 25.064	Y_{11} 25 25.061	Y_{12} 25 25.059
1819	Y_4 6 14 8.485	$w = 1$	... .	... .	Y_6 14 9.570	Y_7 14 9.233	Y_8 14 9.107
	Y_0 6 14 9.166	8	Y_7 14 10.259	Y_9 14 9.460	Y_{10} 14 9.153	Y_{11} 14 9.140	Y_{12} 14 9.139
		16	Y_{10} 14 9.070	Y_9 14 9.136	Y_{10} 14 9.145	Y_{11} 14 9.145	Y_{12} 14 9.138
1811	Y_4 6 2 48.721	$w = 1$	... .	... .	Y_6 2 50.361	Y_7 2 49.463	Y_8 2 49.157
	Y_0 6 2 49.333	8	Y_7 2 51.668	Y_9 2 50.043	Y_{10} 2 49.318	Y_{11} 2 49.277	Y_{12} 2 49.274
		16	Y_{10} 2 49.180	Y_9 2 49.283	Y_{10} 2 49.288	Y_{11} 2 49.288	Y_{12} 2 49.273
1803	Y_4 5 51 28.902	$w = 1$	... .	... .	Y_6 51 30.997	Y_7 51 28.888	Y_8 51 28.219
	Y_0 5 51 28.695	8	Y_7 51 33.240	Y_9 51 30.281	Y_{10} 51 28.711	Y_{11} 51 28.582	Y_{12} 51 28.587
		16	Y_{10} 51 28.466	Y_9 51 28.637	Y_{10} 51 28.623	Y_{11} 51 28.618	Y_{12} 51 28.589
1795	Y_4 5 40 12.974	$w = 1$	... .	... .	Y_6 40 15.065	Y_7 40 10.564	Y_8 40 9.211
	Y_0 5 40 10.397	8	Y_7 40 18.593	Y_9 40 13.726	Y_{10} 40 10.568	Y_{11} 40 10.180	Y_{12} 40 10.219
		16	Y_{10} 40 10.052	Y_9 40 10.389	Y_{10} 40 10.297	Y_{11} 40 10.290	Y_{12} 40 10.227
1787	Y_4 5 29 5.222	$w = 1$	... .	... .	Y_6 29 6.244	Y_7 28 57.334	Y_8 28 54.784
	Y_0 5 28 57.519	8	Y_7 29 11.364	Y_9 29 4.157	Y_{10} 28 58.170	Y_{11} 28 57.106	Y_{12} 28 57.222
		16	Y_{10} 28 56.925	Y_9 28 57.706	Y_{10} 28 57.425	Y_{11} 28 57.416	Y_{12} 28 57.256
1779	Y_4 5 18 10.274	$w = 1$	... .	... .	Y_6 18 8.230	Y_7 17 51.651	Y_8 17 47.106
	Y_0 5 17 52.998	8	Y_7 18 15.075	Y_9 18 5.715	Y_{10} 17 54.895	Y_{11} 17 52.210	Y_{12} 17 52.493
		16	Y_{10} 17 51.794	Y_9 17 53.704	Y_{10} 17 53.035	Y_{11} 17 53.021	Y_{12} 17 52.602
1771	Y_4 5 7 33.100	$w = 1$	... .	... .	Y_6 7 24.642	Y_7 6 55.339	Y_8 6 47.613
	Y_0 5 6 59.542	8	Y_7 7 32.971	Y_9 7 23.095	Y_{10} 7 4.359	Y_{11} 6 58.044	Y_{12} 6 58.616
		16	Y_{10} 6 56.900	Y_9 7 1.459	Y_{10} 7 0.069	Y_{11} 7 0.032	Y_{12} 6 58.938
1763	Y_4 4 57 19.008	$w = 1$	... .	... .	Y_6 56 58.921	Y_7 56 9.323	Y_8 55 56.720
	Y_0 4 56 19.577	8	Y_7 57 7.829	Y_9 57 1.968	Y_{10} 56 30.717	Y_{11} 56 16.736	Y_{12} 56 17.745
		16	Y_{10} 56 13.780	Y_9 56 24.061	Y_{10} 56 21.459	Y_{11} 56 21.328	Y_{12} 56 18.587
1755	Y_4 4 47 33.652	$w = 1$	... .	... .	Y_6 46 54.235	Y_7 45 33.342	Y_8 45 13.502
	Y_0 4 45 55.203	8	Y_7 47 1.745	Y_9 47 9.609	Y_{10} 46 19.216	Y_{11} 45 49.870	Y_{12} 45 51.352
		16	Y_{10} 45 43.018	Y_9 46 4.819	Y_{10} 46 0.346	Y_{11} 45 59.916	Y_{12} 45 53.407

Residuals between the exact Values Y_0 and the Sum of the entire Series $a_0+U^{I}t+U^{II}t^2 \dots U^{XII}t^{12}$.

Employing the same notation as on page 280:—

Epoch.	$t-1875$.		$J=a$		$J=\frac{da}{dt}$		$J=\frac{d^2a}{dt^2}$		$J=\frac{d^3a}{dt^3}$		$J=\frac{d^4a}{dt^4}$	
				s.		s.		s.		s.		s.
1851	− 24	$w=1$	....	....	....	....	Y_0-Y_6	− 0.005	Y_0-Y_7	− 0.005	Y_0-Y_8	− 0.004
		8	Y_0-Y_7	− 0.014	Y_0-Y_9	− 0.006	Y_0-Y_{10}	− 0.003	Y_0-Y_{11}	− 0.004	Y_0-Y_{12}	− 0.004
		16	Y_0-Y_{10}	− 0.002	Y_0-Y_9	− 0.004	Y_0-Y_{10}	− 0.004	Y_0-Y_{11}	− 0.001	Y_0-Y_{12}	− 0.004
1843	− 32	$w=1$	....	....	....	....	Y_0-Y_6	− 0.009	Y_0-Y_7	− 0.005	Y_0-Y_8	− 0.002
		8	Y_0-Y_7	− 0.050	Y_0-Y_9	− 0.012	Y_0-Y_{10}	− 0.002	Y_0-Y_{11}	− 0.001	Y_0-Y_{12}	+ 0.000
		16	Y_0-Y_{10}	+ 0.005	Y_0-Y_9	+ 0.000	Y_0-Y_{10}	+ 0.000	Y_0-Y_{11}	− 0.001	Y_0-Y_{12}	+ 0.000
1835	− 40	$w=1$	....	....	....	....	Y_0-Y_6	− 0.037	Y_0-Y_7	− 0.010	Y_0-Y_8	+ 0.002
		8	Y_0-Y_7	− 0.164	Y_0-Y_9	− 0.037	Y_0-Y_{10}	+ 0.001	Y_0-Y_{11}	+ 0.002	Y_0-Y_{12}	+ 0.003
		16	Y_0-Y_{10}	+ 0.022	Y_0-Y_9	+ 0.005	Y_0-Y_{10}	+ 0.003	Y_0-Y_{11}	+ 0.003	Y_0-Y_{12}	+ 0.004
1827	− 48	$w=1$	....	....	....	....	Y_0-Y_6	− 0.136	Y_0-Y_7	− 0.029	Y_0-Y_8	+ 0.015
		8	Y_0-Y_7	− 0.458	Y_0-Y_9	− 0.111	Y_0-Y_{10}	+ 0.004	Y_0-Y_{11}	+ 0.009	Y_0-Y_{12}	+ 0.010
		16	Y_0-Y_{10}	+ 0.050	Y_0-Y_9	+ 0.012	Y_0-Y_{10}	+ 0.007	Y_0-Y_{11}	+ 0.010	Y_0-Y_{12}	+ 0.012
1819	− 56	$w=1$	....	....	....	....	Y_0-Y_6	− 0.404	Y_0-Y_7	− 0.067	Y_0-Y_8	+ 0.059
		8	Y_0-Y_7	− 1.093	Y_0-Y_9	− 0.294	Y_0-Y_{10}	+ 0.013	Y_0-Y_{11}	+ 0.026	Y_0-Y_{12}	+ 0.027
		16	Y_0-Y_{10}	+ 0.096	Y_0-Y_9	+ 0.030	Y_0-Y_{10}	+ 0.021	Y_0-Y_{11}	+ 0.021	Y_0-Y_{12}	+ 0.028
1811	− 64	$w=1$	....	....	....	....	Y_0-Y_6	− 1.028	Y_0-Y_7	− 0.130	Y_0-Y_8	+ 0.176
		8	Y_0-Y_7	− 2.335	Y_0-Y_9	− 0.710	Y_0-Y_{10}	+ 0.015	Y_0-Y_{11}	+ 0.056	Y_0-Y_{12}	+ 0.059
		16	Y_0-Y_{10}	+ 0.153	Y_0-Y_9	+ 0.050	Y_0-Y_{10}	+ 0.015	Y_0-Y_{11}	+ 0.045	Y_0-Y_{12}	+ 0.060
1803	− 72	$w=1$	....	....	....	....	Y_0-Y_6	− 2.302	Y_0-Y_7	− 0.193	Y_0-Y_8	+ 0.476
		8	Y_0-Y_7	− 4.545	Y_0-Y_9	− 1.586	Y_0-Y_{10}	− 0.016	Y_0-Y_{11}	+ 0.113	Y_0-Y_{12}	+ 0.108
		16	Y_0-Y_{10}	+ 0.229	Y_0-Y_9	+ 0.058	Y_0-Y_{10}	+ 0.072	Y_0-Y_{11}	+ 0.077	Y_0-Y_{12}	+ 0.106
1795	− 80	$w=1$	....	....	....	....	Y_0-Y_6	− 4.668	Y_0-Y_7	− 0.167	Y_0-Y_8	+ 1.186
		8	Y_0-Y_7	− 8.196	Y_0-Y_9	− 3.329	Y_0-Y_{10}	− 0.171	Y_0-Y_{11}	+ 0.217	Y_0-Y_{12}	+ 0.178
		16	Y_0-Y_{10}	+ 0.345	Y_0-Y_9	+ 0.008	Y_0-Y_{10}	+ 0.100	Y_0-Y_{11}	+ 0.107	Y_0-Y_{12}	+ 0.170
1787	− 88	$w=1$	....	....	....	....	Y_0-Y_6	− 8.725	Y_0-Y_7	+ 0.185	Y_0-Y_8	+ 2.735
		8	Y_0-Y_7	−13.845	Y_0-Y_9	− 6.638	Y_0-Y_{10}	− 0.651	Y_0-Y_{11}	+ 0.413	Y_0-Y_{12}	+ 0.297
		16	Y_0-Y_{10}	+ 0.594	Y_0-Y_9	− 0.187	Y_0-Y_{10}	+ 0.094	Y_0-Y_{11}	+ 0.103	Y_0-Y_{12}	+ 0.263
1779	− 96	$w=1$	....	....	....	....	Y_0-Y_6	−15.232	Y_0-Y_7	+ 1.347	Y_0-Y_8	+ 5.892
		8	Y_0-Y_7	−22.077	Y_0-Y_9	−12.717	Y_0-Y_{10}	− 1.897	Y_0-Y_{11}	+ 0.788	Y_0-Y_{12}	+ 0.505
		16	Y_0-Y_{10}	+ 1.204	Y_0-Y_9	− 0.706	Y_0-Y_{10}	− 0.037	Y_0-Y_{11}	− 0.023	Y_0-Y_{12}	+ 0.396
1771	−104	$w=1$	....	....	....	....	Y_0-Y_6	−25.100	Y_0-Y_7	+ 4.203	Y_0-Y_8	+11.929
		8	Y_0-Y_7	−33.429	Y_0-Y_9	−23.553	Y_0-Y_{10}	− 4.817	Y_0-Y_{11}	+ 1.498	Y_0-Y_{12}	+ 0.926
		16	Y_0-Y_{10}	+ 2.642	Y_0-Y_9	− 1.917	Y_0-Y_{10}	− 0.527	Y_0-Y_{11}	− 0.490	Y_0-Y_{12}	+ 0.604
1763	−112	$w=1$	....	....	....	....	Y_0-Y_6	−39.344	Y_0-Y_7	+10.254	Y_0-Y_8	+22.857
		8	Y_0-Y_7	−48.252	Y_0-Y_9	−42.391	Y_0-Y_{10}	−11.140	Y_0-Y_{11}	+ 2.841	Y_0-Y_{12}	+ 1.832
		16	Y_0-Y_{10}	+ 5.797	Y_0-Y_9	− 4.484	Y_0-Y_{10}	− 1.882	Y_0-Y_{11}	− 1.751	Y_0-Y_{12}	+ 0.990
1755	−120	$w=1$	....	....	....	....	Y_0-Y_6	−59.032	Y_0-Y_7	+21.861	Y_0-Y_8	+41.701
		8	Y_0-Y_7	−66.542	Y_0-Y_9	−74.406	Y_0-Y_{10}	−24.013	Y_0-Y_{11}	+ 5.333	Y_0-Y_{12}	+ 3.851
		16	Y_0-Y_{10}	+12.185	Y_0-Y_9	− 9.616	Y_0-Y_{10}	− 5.143	Y_0-Y_{11}	− 4.713	Y_0-Y_{12}	+ 1.796

The following conclusions are drawn from an examination of these residuals. They relate strictly to the star Groombridge 1119, but they will apply in a general way to all stars having nearly the same declination.

(*a*) Between $t = 0$ and $t = 32$ the correspondence between the results obtained from the Bohnenberger equations and those found by the development by Taylor's Theorem is sufficiently exact, whatever quantity is taken as the initial function in the computation of the differential coefficients, and whatever value is given to w, except when the initial function is α.

(*b*) For any date earlier than 1835 the development fails when $w = 1$, while the limit when $w = 8$ may be placed at about 1825.

(*c*) Between the limits $w = 1$ and $w = 16$ every form of development fails when t exceeds fifty years. From this point the magnitude of the residuals varies with the choice of the quantity taken as the initial function, and with the value of w.

(*d*) Variations in the value of w produce the least effect when $J = \frac{d^4 \alpha}{d t^4}$, and the greatest effect when $J = \alpha$.

(*e*) Whatever quantity is taken as the initial function in the computation of the differential coefficients, there is a substantial agreement in the values of the residuals between $t = 0$ and $t = 50$ when $w = 16$.

(*f*) When α is taken as the initial function, w should never be taken less than 16 when t exceeds 20 years, and a new equinox should be chosen when t exceeds 40 years.

(*g*) Between $t = 0$ and $t = 80$, $\frac{d\alpha}{dt}$ may be advantageously taken as the initial function in the computation of the differential coefficients, both on account of the smallness of the residuals for $w = 16$, and on account of the comparatively trifling labor involved in the computation.

(*h*) Notwithstanding the general increase in the accuracy of the development with an increase in the number of the terms of the series, the gain when t exceeds 40 years is so slight that it will be better in any case to change the equinox at intervals of 30 years. In computing the new coefficients, $\frac{d\alpha}{dt}$ may be advantageously selected as the initial function. It will be sufficient to carry the computation to the sixth term inclusive if $w = 16$.

(*i*) It will be seen, therefore, that the advantage gained by the increase in the number of terms of the series may be counterbalanced by the effect of the unavoidable errors in the logarithmic computation of the initial functions. Hence, it may happen that it will be a positive disadvantage to extend the development beyond a certain limit. This limit appears, in the present case, to be near the seventh term when $w = 16$ and $t = 50$.

Development of the Functions α and δ by Mechanical Quadratures.

The differential coefficients already computed hold true only for the instant of time at which the initial functions α and δ are assumed to be true. In the series of differences obtained from these functions, the differential coefficients all fall upon the same horizontal line.

In order to obtain the summed series which will represent the values of α and δ at any assumed epoch of the constants of the precession, it will be necessary to find the values of the differential coefficients which correspond to the instant $t + \frac{1}{2}$ or $t - \frac{1}{2}$.

If the series does not extend beyond 24 years, the fourth term may be taken as a constant. The coefficients may be converted into differences from which the summation may be directly made by the following relations:

Functions for the Instant t_0.	Equivalent Functions for the Instant $t \pm \frac{1}{2}$.
$\Delta_4 = \dfrac{d^4\alpha}{dt^4} = \Delta^{IV}$	$\Delta_4 = \Delta^{IV} = \alpha$ constant
$\Delta_3 = \dfrac{d^3\alpha}{dt^3} =$	$\Delta_3 = \Delta^{III}$
$\Delta_2 = \dfrac{d^2\alpha}{dt^2} = \Delta^{II}$	$\Delta_2 = \Delta^{II} + \frac{1}{12}\Delta^{IV}$
$\Delta_1 = \dfrac{d\alpha}{dt} = \Delta^{I}$	$\Delta_1 = \Delta^{I} + \frac{1}{6}\Delta^{III}$
	$\Delta_1 + \frac{1}{2} = \Delta_1 + \frac{1}{2}\Delta_2$

From the example given on page 247 we have the following data:

Epoch.	α	$\frac{d\alpha}{dt}$	$\frac{d^2\alpha}{dt^2}$	$\frac{d^3\alpha}{dt^3}$	$\frac{d^4\alpha}{dt^4}$
	h. m. s.	s.	s.	s.	s.
1875.0	7 29 5.631000	73.51432400	−0.30237888	−0.00203746	+0.00008334

Whence for the instant $t \pm \frac{1}{2}$

$$\begin{aligned}
\Delta_4 &= +\ \overset{s.}{0}.00008334 \\
\Delta_3 &= -\ 0.00203746 \\
\Delta_2 &= -\ 0.30237888 + \frac{\overset{s.}{0}.00008334}{12} = -\ \overset{s.}{0}.30237194 \\
\Delta_1 &= +73.51432400 - \frac{0.00203746}{6} = +73.51398442
\end{aligned}$$

We have therefore:

Epoch.	α	Δ_1	Δ_2	Δ_3	Δ_4
	h. m. s.	s.	s.	s.	s.
1875.0	7 29 5.63100000	+73.51398442	−0.30237194	−0.00203746	+0.00008334
		+73.36279845		−0.00199580	
1876.0	7 30 18.99379845		−0.30436774		

The summation in either direction from 1875 may now be continued by the successive additions or subtractions of the differences.

The application of this method will be illustrated by the computation of α for each year from 1875 to 1899.

Epoch.	α	Δ_1	Δ_2	Δ_3	Δ_4
	h. m. s.				
1875	7 29 5.63100000				+0.00008334
		+73.36279845		−0.00199580	
1876	7 30 18.99379845		−0.30436774		+0.00008334
		+73.05843071		−0.00191246	
1877	7 31 32.05222916		−0.30628020		+0.00008334
		+72.75215051		−0.00182912	
1878	7 32 44.80437967		−0.30810932		+0.00008334
		+72.44404119		−0.00174578	
1879	7 33 57.24842086		−0.30985510		+0.00008334
		+72.13418609		−0.00166244	
1880	7 35 9.38260695		−0.31151754		+0.00008334
		+71.82266855		−0.00157910	
1881	7 36 21.20527550		−0.31309664		+0.00008334
		+71.50957191		−0.00149576	
1882	7 37 32.71484741		−0.31459240		+0.00008334
		+71.19497951		−0.00141242	
1883	7 38 43.90982692		−0.31600482		+0.00008334
		+70.87897469		−0.00132908	
1884	7 39 54.78880161		−0.31733390		+0.00008334
		+70.56164079		−0.00124574	
1885	7 41 5.35044240		−0.31857964		+0.00008334
		+70.24306115		−0.00116240	
1886	7 42 15.59350355		−0.31974204		+0.00008334
		+69.92331911		−0.00107906	
1887	7 43 25.51682266		−0.32082110		+0.00008334
		+69.60249801		−0.00099572	

Epoch.	α			Δ_1	Δ_2	Δ_3	Δ_4
	h.	m.	s.	+69.60249801		−0.00099572	
1888	7	44	35.11932067		−0.32181682		+0.00008334
				+69.28068119		−0.00091238	
1889	7	45	44.40000186		−0.32272920		+0.00008334
				+68.95795199		−0.00082904	
1890	7	46	53.35795385		−0.32355824		+0.00008334
				+68.63439375		−0.00074570	
1891	7	48	1.99234750		−0.32430394		+0.00008334
				+68.31008981		−0.00066236	
1892	7	49	10.30243731		−0.32496630		+0.00008334
				+67.98512351		−0.00057902	
1893	7	50	18.28756082		−0.32554532		+0.00008334
				+67.65957819		−0.00049568	
1894	7	51	25.94713901		−0.32604100		+0.00008334
				+67.33353719		−0.00041234	
1895	7	52	33.28067620		−0.32645334		+0.00008334
				+67.00708385		−0.00032900	
1896	7	53	40.28776005		−0.32678234		+0.00008334
				+66.68030151		−0.00024566	
1897	7	54	46.96806156		−0.32702800		+0.00008334
				+66.35327351		−0.00016232	
1898	7	55	53.32133507		−0.32719032		+0.00008334
				+66.02608319		−0.00007898	
1899	7	56	59.34741826		−0.32726930		

It will be seen that the result for 1899 agrees with that already found to the fourth decimal place.

Reduction of α and δ from any Time t_0 to any Time t' by Means of the Precession for the Mean Interval.

Main has given the following expressions (Mem. Roy. Astron. Soc., XIX. pp. 127, 128, 1851), which he has derived from the method printed out by O. Struve in his "Bestimmung der Constante der Præcession" (Mém. de l'Acad. Imp. de St. Petersburgh, 6th Series, III. p. 49, 1841).

Let p_1, p_2, p_3, p_4, p_5, represent the values of the precessions for the times t, $2t$, $3t$, $4t$, $5t$, and let P_3, P_4, and P_5 represent the precessions for the mean intervals.

Then for the total effect of the precession at the end of any given time t, we have:

For 3 equidistant intervals $\alpha = \alpha_0 + \frac{1}{6}\,[p_1 + 4p_2 + p_3]\,t = \alpha_0 + P_3\,t$ (54)

For 4 equidistant intervals $\alpha = \alpha_0 + \frac{1}{8}\,[p_1 + 3p_2 + 3p_3 + p_4]\,t = \alpha_0 + P_4\,t$ (55)

For 5 equidistant intervals $\alpha = \alpha_0 + \frac{1}{90}\,[7p_1 + 32p_2 + 12p_3 + 32p_4 + 7p_5]\,t = \alpha_0 + P_5\,t$ (56)

And similarly for δ.

The values of $p_1 \ldots p_5$ in the application of this method should, in practice, be computed from the co-ordinates derived directly from the observations. If, however, there are not a sufficient number of observations available for the formation of the equal intervals, the first three or four values of α derived by the method already described may be used for the computation of the corresponding values of p.

After this the values of p can be carried forward by differences with sufficient accuracy for the computation of the values of α and δ in advance of the last value computed. It will be necessary to carry the reductions for α and δ along together.

For the computation of the values p_1, p_2, p_3, &c., equations (16) and (20) become:

$$\frac{d\,\alpha}{d\,t} = (m + m'\,t) + (n + n'\,t)\sin\alpha\tan\delta \tag{57}$$

$$\frac{d\,\delta}{d\,t} = (n + n'\,t)\cos\alpha \tag{58}$$

The values of $(m + m'\,t)$ and $\log(n + n'\,t)$ can be conveniently written in tabular form. The values for intervals of four years from 1875 to 1899 are as follows:—

Epoch.	$[m + m'\,t]$	$[\log n + n'\,t]$	$\log\,[n + n'\,t]$
	s.	s.	$''$
1875	3.0722450	0.1261147	1.3022060
1879	3.0723209	0.1261075	1.3021988
1883	3.0723969	0.1261003	1.3021916
1887	3.0724729	0.1260931	1.3021844
1891	3.0725488	0.1260859	1.3021772
1895	3.0726248	0.1260787	1.3021700
1899	3.0727008	0.1260715	1.3021628
	&c.	&c.	&c.

In illustration of the application of this method of transferring the co-ordinates α and δ for any epoch t_0 to any epoch t', we select as provisional values of α and δ those derived by computation from the differential coefficients to the fourth term inclusive, from 1875 to 1899. They are given on page 268. The corresponding values of p_1, p_2, p_3, have been computed from equations (57) and (58).

	α			$\frac{d\alpha}{dt}$	δ			$\frac{d\delta}{dt}$
	h.	m.	s.	s.	°	′	″	″
1875	7	29	5.631	+ 73.514324	+ 88	59	37.69	− 7.601
1879	7	33	57.248	+ 72.289466	+ 88	59	6.50	− 7.993
1883	7	38	43.910	+ 71.037178	+ 88	58	33.76	− 8.375
1887	7	43	25.517	+ 69.762627	+ 88	57	59.52	− 8.746
1891	7	48	1.992	+ 68.470504	+ 88	57	23.81	− 9.107
1895	7	52	33.281	+ 67.165522	+ 88	56	46.68	− 9.458
1899	7	56	59.347	+ 65.851860	+ 88	56	8.17	− 9.798

We now compute the values of α for the years 1883 to 1899 by formulæ (54):

$$\begin{array}{lrr} & & \text{s.} \\ \text{For } 1875 & p_1 = & +\ 73.514324 \\ 1879 & 4\,p_2 = & +289.157864 \\ 1883 & p_3 = & +\ 71.037178 \\ \hline & \text{Sum} & +433.709366 \end{array}$$

$$\begin{array}{lrrrr} & & \text{h.} & \text{m.} & \text{s.} \\ & P_3 = & +0 & 0 & 72.284894 \\ & 8\,P_3 = & +0 & 9 & 38.2791 \\ & \alpha_0 = & 7 & 29 & 5.6310 \\ \text{For } 1883 & \alpha = & 7 & 38 & 43.9101 \end{array}$$

$$\begin{array}{lrr} & & \text{s.} \\ \text{For } 1879 & p_1 = & +\ 72.289466 \\ 1883 & 4\,p_2 = & +284.148712 \\ 1887 & p_3 = & +\ 69.762627 \\ \hline & \text{Sum} & +426.200805 \end{array}$$

$$\begin{array}{lrrrr} & & \text{h.} & \text{m.} & \text{s.} \\ & P_3 = & +0 & 0 & 71.033468 \\ & 8\,P_3 = & +0 & 9 & 28.2677 \\ & \alpha_0 = & 7 & 33 & 57.2480 \\ \text{For } 1887 & \alpha = & 7 & 43 & 25.5157 \end{array}$$

$$\begin{array}{lrr} & & \text{s.} \\ \text{For } 1883 & p_1 = & +\ 71.037178 \\ 1887 & 4\,p_2 = & +279.050508 \\ 1891 & p_3 = & +\ 68.470504 \\ \hline & \text{Sum} & +418.558190 \end{array}$$

$$\begin{array}{lrrrr} & & \text{h.} & \text{m.} & \text{s.} \\ & P_3 = & +0 & 0 & 69.759698 \\ & 8\,P_3 = & +0 & 9 & 18.0776 \\ & \alpha_0 = & 7 & 38 & 43.9101 \\ \text{For } 1891 & \alpha = & 7 & 48 & 1.9877 \end{array}$$

$$\begin{array}{lrr} & & \text{s.} \\ \text{For } 1887 & p_1 = & +\ 69.762627 \\ 1891 & 4\,p_2 = & +273.882016 \\ 1895 & p_3 = & +\ 67.165522 \\ \hline & \text{Sum} & +410.810165 \end{array}$$

$$\begin{array}{lrrrr} & & \text{h.} & \text{m.} & \text{s.} \\ & P_3 = & +0 & 0 & 68.468361 \\ & 8\,P_3 = & +0 & 9 & 7.7469 \\ & \alpha_0 = & 7 & 43 & 25.5157 \\ \text{For } 1895 & \alpha = & 7 & 52 & 33.2626 \end{array}$$

From this point the approximate values of $\frac{d\alpha}{dt}$ required for the computation of the next and the following dates can be found from the successive orders of differences of $\frac{d\alpha}{dt}$ already found. Each result for α should be verified by a second computation before proceeding to the next in order. The values of the precessions in declination vary so slowly that a second computation will not be necessary.

We now have:

	α	$\frac{d\alpha}{dt}$	Δ_1	Δ_2	Δ_3	δ	$\frac{d\delta}{dt}$	Δ_1	Δ_2
	h. m. s.	s.				° ′ ″	″		
1875	7 29 5.6310	+73.5143				+88 59 37.69	−7.601		
			−1.2248					−0.392	
1879	7 33 57.2480	+72.2895		−0.0275		+88 59 6.50	−7.993		+0.010
			−1.2523		+0.0052			−0.382	
1883	7 38 43.9101	+71.0372		−0.0223		+88 58 33.76	−8.375		+0.011
			−1.2746		+0.0048			−0.371	
1887	7 43 25.5157	+69.7626		−0.0175		+88 57 59.52	−8.746		+0.010
			−1.2921		+0.0046			−0.361	
1891	7 48 1.9877	+68.4705		−0.0129		+88 57 23.81	−9.107		+0.010
			−1.3050					−0.351	
1895	7 52 33.2626	+67.1655				+88 56 46.68	−9.458		

Assuming $+0^s.0044$ for the third difference of $\frac{d\alpha}{dt}$ opposite 1893, and $+0''.010$ for the second difference of $\frac{d\delta}{dt}$, we have:

	α	$\frac{d\alpha}{dt}$	Δ_1	Δ_2	Δ_3	δ	$\frac{d\delta}{dt}$	Δ_1	Δ_2
	h. m. s.	s.				° ′ ″	″		
1891	7 48 1.9877	+68.4705		−0.0129		+88 57 23.81	− 9.107		+0.010
			−1.3050		+0.0044			−0.351	
1895	7 52 33.2626	+67.1655		−0.0085		+88 56 46.68	− 9.458		+0.011
			−1.3135		+0.0042			−0.340	
1899	7 56 59.3003	+65.8520		−0.0043		+88 56 8.17	− 9.798		+0.010
			−1.3178		+0.0040			−0.330	
1903	8 1 20.0768	+64.5342		−0.0003		+88 55 28.32	−10.128		+0.010
			−1.3181					−0.320	
1907	8 5 35.7067	+63.2161				+88 54 47.17	−10.448		

After proceeding thus far, it will be advisable to recompute the values of $\frac{d\alpha}{dt}$ and $\frac{d\delta}{dt}$, and the resulting values of α and δ. Then, with the more accurate series of differences, the computation for several intervals in advance can be safely made. It will be found that the values of δ and $\frac{d\delta}{dt}$ require no change. For α and $\frac{d\alpha}{dt}$ we find:

Epoch.	α			$\frac{d\alpha}{dt}$	Δ_1	Δ_2	Δ_3
	h.	m.	s.	s.	s.	s.	s.
1875	7	29	5.6310	+73.51432			
					−1.22485		
1879	7	33	57.2480	+72.28947		−0.02744	
					−1.25229		+0.00515
1883	7	38	43.9101	+71.03718		−0.02229	
					−1.27458		+0.00480
1887	7	43	25.5157	+69.76260		−0.01749	
					−1.29207		+0.00460
1891	7	48	1.9877	+68.47053		−0.01289	
					−1.30496		+0.00425
1895	7	52	33.2626	+67.16557		−0.00864	
					−1.31360		+0.00406
1899	7	56	59.3003	+65.85197		−0.00458	
					−1.31818		+0.00369
1903	8	1	20.0709	+64.53379		−0.00089	
					−1.31907		
1907	8	5	35.5693	+63.21472			

As a further illustration of the application of formulæ (54), (55), and (56), we compute the value of α for 1911 from the values of $\frac{d\alpha}{dt}$ for 1895, 1903, 1911, by formula (54); for 1887, 1895, 1903, and 1911, by formula (55); and for 1879, 1887, 1895, 1903, and 1911, by formula (56). The value of $\frac{d\alpha}{dt}$ for 1911 is carried forward from that for 1907 by means of the third difference $+0^s.00341$, giving $\frac{d\alpha}{dt} = +61^s.89817$.

$$\begin{array}{lrlrrr}
 & & & & & \text{s.} \\
1895 & p_1 = & + & & & 67.16557 \\
1903 & 4p_2 = & + & & & 258.13516 \\
1911 & p_3 = & + & & & 61.89817 \\
 & \text{Sum} = & + & & & 387.19890 \\
 & P_3 = & + & & & 64.53315 \\
 & & & \text{h.} & \text{m.} & \text{s.} \\
 & 16P_3 = & + & 0 & 17 & 12.5304 \\
 & \alpha_0 = & & 7 & 52 & 33.2626 \\
\text{For 1911} & \alpha = & & 8 & 9 & 45.7930
\end{array}$$

$$\begin{array}{lrlrrr}
 & & & & & \text{s.} \\
1887 & p_1 = & + & & & 69.76260 \\
1895 & 3p_2 = & + & & & 201.49671 \\
1903 & 3p_3 = & + & & & 193.60137 \\
1911 & p_4 = & + & & & 61.89817 \\
 & \text{Sum} = & + & & & 526.75885 \\
 & P_4 = & + & & & 65.84486 \\
 & & & \text{h.} & \text{m.} & \text{s.} \\
 & 24P_4 = & + & 0 & 26 & 20.2766 \\
 & \alpha_0 = & & 7 & 43 & 25.5157 \\
\text{For 1911} & \alpha = & & 8 & 9 & 45.7923
\end{array}$$

$$\begin{array}{lrlrrr}
 & & & & & \text{s.} \\
1879 & 7p_1 = & + & & & 506.02629 \\
1887 & 32p_2 = & + & & & 2232.40320 \\
1895 & 12p_3 = & + & & & 805.98684 \\
1903 & 32p_4 = & + & & & 2065.08128 \\
1911 & 7p_5 = & + & & & 433.28719 \\
 & \text{Sum} = & + & & & 6042.78480 \\
 & P_5 = & + & & & 67.14205 \\
 & & & \text{h.} & \text{m.} & \text{s.} \\
 & 32P_5 = & + & 0 & 35 & 48.5457 \\
 & \alpha_0 = & & 7 & 33 & 57.2480 \\
\text{For 1911} & \alpha = & & 8 & 9 & 45.7937
\end{array}$$

Development of the Functions α and δ by Means of two or more Partial Series expressed in Terms of the Ascending Powers of the Time.

It has been shown that it is impossible to obtain the exact development of the primary functions for stars within one degree of the pole when the time exceeds forty years, even in the most favorable case which can occur.

The time at which the values of the initial functions derived from the development by Taylor's Theorem begin to deviate from those derived from equations (6) may be extended many years by means of a secondary series which represents the residuals between the exact co-ordinates and those obtained with any assumed limit to the terms of the series.

Let $Y_0 =$ the values of the functions α or δ derived from equations (6).

$Y_3, Y_4, Y_5, \ldots Y_{12} =$ the values of α or δ derived from the development which terminates with the 3d, 4th, 5th to the 12th term.

We shall then have a series of residuals $Y_0 - Y_3$, $Y_0 - Y_4$, $Y_0 - Y_5$, . . . $Y_0 - Y_{12}$, any one of which may be represented by a series similar in form to the primary series from which the residuals have been obtained.

It is to be remarked, however, that this second series will not be continuous with respect to the first.

If these residuals are obtained for the equidistant intervals w, $2w$, $3w$, $4w$, &c. years, we shall have a series of equations in which the number of the equations is the same as the number of the unknown quantities. We shall thus obtain an exact representation of the residuals for the intervals chosen, and a close approximation to the true values for any intermediate interval which does not much exceed twenty years.

If the residuals really follow the law expressed by Taylor's Theorem, we shall also be able to extend the agreement considerably beyond the limit for the largest value of nw employed, n being the coefficient of w.

Let $a =$ the value of $Y_0 - (Y_3 \ldots Y_{12})$ for w years,
$b =$ the value of $Y_0 - (Y_3 \ldots Y_{12})$ for $2w$ years,
$c =$ the value of $Y_0 - (Y_3 \ldots Y_{12})$ for $3w$ years,
$d =$ the value of $Y_0 - (Y_3 \ldots Y_{12})$ for $4w$ years,
$e =$ the value of $Y_0 - (Y_3 \ldots Y_{12})$ for $5w$ years,
$f =$ the value of $Y_0 - (Y_3 \ldots Y_{12})$ for $6w$ years, &c.

We shall have by Taylor's Theorem:

For Three Equidistant Values of w.

If $\frac{d' \alpha}{d t} = x$, $\frac{d'^2 \alpha}{d t^2} = y$, and $\frac{d'^3 \alpha}{d t^3} = z$,

$$\begin{aligned} w x + \frac{1}{2} w^2 y + \frac{1}{6} w^3 z &= a \\ w x + w^2 y + \frac{2}{3} w^3 z &= \frac{b}{2} \\ w x + \frac{3}{2} w^2 y + \frac{3}{2} w^3 z &= \frac{c}{3} \end{aligned} \tag{59}$$

Whence

$$\begin{aligned} x &= \frac{1}{w} [3 a - \frac{3}{2} b + \frac{1}{3} c] \\ y &= \frac{1}{w^2} [4 b - 5 a - c] \\ z &= \frac{1}{w^3} [3 a - 3 b + c] \end{aligned} \tag{60}$$

For Four Equidistant Values of w.

If $\frac{d' \alpha}{d t} = v$, $\frac{d'^2 \alpha}{d t^2} = x$, $\frac{d'^3 \alpha}{d t^3} = y$, $\frac{d'^4 \alpha}{d t^4} = z$, we have

$$\begin{aligned} w v + \frac{1}{2} w^2 x + \frac{1}{6} w^3 y + \frac{1}{24} w^3 z &= a \\ w v + w^2 x + \frac{2}{3} w^3 y + \frac{1}{3} w^4 z &= \frac{b}{2} \\ w v + \frac{3}{2} w^2 x + \frac{3}{2} w^3 y + \frac{9}{8} w^4 z &= \frac{c}{3} \\ w v + 2 w^2 x + \frac{8}{3} w^3 y + \frac{8}{3} w^4 z &= \frac{d}{4} \end{aligned} \tag{61}$$

Whence

$$\begin{aligned} v &= \frac{1}{w} \left[4 a - 3 b + \frac{4}{3} c - \frac{1}{4} d\right] \\ x &= \frac{1}{w^2} \left[\frac{11}{12} d + \frac{19}{2} b - \frac{14}{3} c - \frac{26}{3} a\right] \\ y &= \frac{1}{w^3} \left[9 a - 12 b + 7 c - \frac{3}{2} d\right] \\ z &= \frac{1}{w^4} \left[d - 4 c + 6 b - 4 a\right] \end{aligned} \tag{62}$$

For Five Equidistant Values of w.

If $\frac{d'\alpha}{dt} = u, \quad \frac{d'^2\alpha}{dt^2} = v, \quad \frac{d'^3\alpha}{dt^3} = x, \quad \frac{d'^4\alpha}{dt^4} = y, \quad \frac{d'^5\alpha}{dt^5} = z,$ we have

$$\left.\begin{aligned}
w\,u + \frac{1}{2}\,w^2 v + \frac{1}{6}\,w^3 x + \frac{1}{24}\,w^4 y + \frac{1}{120}\,w^5 z &= a \\
w\,u + w^2 v + \frac{2}{3}\,w^3 x + \frac{1}{3}\,w^4 y + \frac{2}{15}\,w^5 z &= \frac{b}{2} \\
w\,u + \frac{3}{2}\,w^2 v + \frac{3}{2}\,w^3 x + \frac{9}{8}\,w^4 y + \frac{27}{40}\,w^5 z &= \frac{c}{3} \\
w\,u + 2\,w^2 v + \frac{8}{3}\,w^3 x + \frac{8}{3}\,w^4 y + \frac{32}{15}\,w^5 z &= \frac{d}{4} \\
w\,u + \frac{5}{2}\,w^2 v + \frac{25}{6}\,w^3 x + \frac{125}{24}\,w^4 y + \frac{125}{24}\,w^5 z &= \frac{e}{5}
\end{aligned}\right\} \tag{63}$$

Whence

$$\left.\begin{aligned}
u &= \frac{1}{w}\left[5\,a - 5\,b + \frac{10}{3}\,c - \frac{5}{4}\,d + \frac{e}{5}\right] \\
v &= \frac{1}{w^2}\left[\frac{107}{6}\,b - \frac{77}{6}\,a - 13\,c + \frac{61}{12}\,d - \frac{5}{6}\,e\right] \\
x &= \frac{1}{w^3}\left[\frac{71}{4}\,a - \frac{59}{2}\,b + \frac{49}{2}\,c - \frac{41}{4}\,d + \frac{7}{4}\,e\right] \\
y &= \frac{1}{w^4}\left[26\,b - 14\,a - 24\,c + 11\,d - 2\,e\right] \\
z &= \frac{1}{w^5}\left[5\,a - 10\,b + 10\,c - 5\,d + e\right]
\end{aligned}\right\} \tag{64}$$

For Six Equidistant Values of w.

If $\frac{d'\alpha}{dt} = s, \quad \frac{d'^2\alpha}{dt^2} = u, \quad \frac{d'^3\alpha}{dt^3} = v, \quad \frac{d'^4\alpha}{dt^4} = x, \quad \frac{d'^5\alpha}{dt^5} = y, \quad \frac{d'^6\alpha}{dt^6} = z,$ we have

$$\left.\begin{aligned}
w\,s + \frac{1}{2}\,w^2 u + \frac{1}{6}\,w^3 v + \frac{1}{24}\,w^4 x + \frac{1}{120}\,w^5 y + \frac{1}{720}\,w^6 z &= a \\
w\,s + w^2 u + \frac{2}{3}\,w^3 v + \frac{1}{3}\,w^4 x + \frac{2}{15}\,w^5 y + \frac{2}{45}\,w^6 z &= \frac{b}{2} \\
w\,s + \frac{3}{2}\,w^2 u + \frac{3}{2}\,w^3 v + \frac{9}{8}\,w^4 x + \frac{27}{40}\,w^5 y + \frac{27}{80}\,w^6 z &= \frac{c}{3} \\
w\,s + 2\,w^2 u + \frac{8}{3}\,w^3 v + \frac{8}{3}\,w^4 x + \frac{32}{15}\,w^5 y + \frac{64}{45}\,w^6 z &= \frac{d}{4} \\
w\,s + \frac{5}{2}\,w^2 u + \frac{25}{6}\,w^3 v + \frac{125}{24}\,w^4 x + \frac{125}{24}\,w^5 y + \frac{625}{144}\,w^6 z &= \frac{e}{5} \\
w\,s + 3\,w^2 u + 6\,w^3 v + 9\,w^4 x + \frac{54}{5}\,w^5 y + \frac{54}{5}\,w^6 z &= \frac{f}{6}
\end{aligned}\right\} \tag{65}$$

Whence

$$\begin{aligned}
s &= \frac{1}{w}\left[6\,a - \frac{15}{2}\,b + \frac{20}{3}\,c - \frac{15}{4}\,d + \frac{6}{5}\,e - \frac{1}{6}\,f\right] \\
u &= \frac{1}{w^2}\left[\frac{117}{4}\,b - \frac{87}{5}\,a - \frac{254}{9}\,c + \frac{33}{2}\,d - \frac{27}{5}\,e + \frac{137}{180}\,f\right] \\
v &= \frac{1}{w^3}\left[29\,a - \frac{461}{8}\,b + 62\,c - \frac{307}{8}\,d + 13\,e - \frac{15}{8}\,f\right] \\
x &= \frac{1}{w^4}\left[\frac{137}{2}\,b - 31\,a - \frac{242}{3}\,c + \frac{107}{2}\,d - 19\,e + \frac{17}{6}\,f\right] \\
y &= \frac{1}{w^5}\left[20\,a - \frac{95}{2}\,b + 60\,c - \frac{85}{2}\,d + 16\,e - \frac{5}{2}\,f\right] \\
z &= \frac{1}{w^6}\left[15\,b - 6\,a - 20\,c + 15\,d - 6\,e + f\right]
\end{aligned} \tag{66}$$

The final equation for α will then become:

$$\begin{aligned}
\alpha = \alpha_0 &+ \frac{d\alpha}{dt}\,t + \frac{1}{2}\,\frac{d^2\alpha}{dt^2}\,t^2 + \frac{1}{6}\,\frac{d^3\alpha}{dt^3}\,t^3 + \frac{1}{24}\,\frac{d^4\alpha}{dt^4}\,t^4 + \frac{1}{120}\,\frac{d^5\alpha}{dt^5}\,t^5 + \frac{1}{720}\,\frac{\alpha^6\alpha}{dt^6}\,t^6, \text{ \&c.} \\
&+ \frac{d'\alpha}{dt}\,t + \frac{1}{2}\,\frac{d'^2\alpha}{dt^2}\,t^2 + \frac{1}{6}\,\frac{d'^3\alpha}{dt^3}\,t^3 + \frac{1}{24}\,\frac{d'^4\alpha}{dt^4}\,t^4 + \frac{1}{120}\,\frac{d'^5\alpha}{dt^5}\,t^5 + \frac{1}{720}\,\frac{d'^6\alpha}{dt^6}\,t^6, \text{ \&c.} \\
= \alpha_0 &+ \left(\frac{d\alpha}{dt} + \frac{d'\alpha}{dt}\right) + \frac{1}{2}\left(\frac{d^2\alpha}{dt^2} + \frac{d'^2\alpha}{dt^2}\right)t^2 + \frac{1}{6}\left(\frac{d^3\alpha}{dt^3} + \frac{d'^3\alpha}{dt^3}\right)t^3 + \frac{1}{24}\left(\frac{d^4\alpha}{dt^4} + \frac{d'^4\alpha}{dt^4}\right), \text{\&c.,}
\end{aligned}$$

and similarly for δ.

As an illustration of the application of this method, we select the values of $Y_0 - Y_4$ given on page 267. For intervals of sixteen years from 1875 to 1779 we have:

Epoch.	t	$Y_0 - Y_4$	Epoch.	t	$Y_0 - Y_4$
		s.			s.
1859	16	$a = -0.001$	1811	64	$d = +\ 0.612$
1843	32	$b = +0.102$	1795	80	$e = -\ 2.577$
1827	48	$c = +0.480$	1779	96	$f = -17.276$

Whence by equations (66)

$$\begin{aligned}
&& \text{s.} \\
+6\,a &=& -0.00600 \\
-\tfrac{15}{2}\,b &=& -0.76500 \\
+\tfrac{20}{3}\,c &=& +3.20000 \\
-\tfrac{15}{4}\,d &=& -2.29500 \\
+\tfrac{6}{5}\,e &=& -3.09240 \\
-\tfrac{1}{6}\,f &=& \underline{+2.87933} \\
\text{Sum} &=& -0.07907
\end{aligned}$$

$$\begin{aligned}
&& \text{s.} \\
+\tfrac{117}{4}\,b &=& +\ 2.98350 \\
-\tfrac{87}{5}\,a &=& +\ 0.01740 \\
-\tfrac{254}{9}\,c &=& -13.54667 \\
+\tfrac{33}{2}\,d &=& +10.09800 \\
-\tfrac{27}{5}\,e &=& +13.91580 \\
+\tfrac{137}{180}\,f &=& \underline{-13.14896} \\
\text{Sum} &=& +\ 0.31907
\end{aligned}$$

$$\begin{aligned}
&& \text{s.} \\
+29\,a &=& -\ 0.02900 \\
-\tfrac{461}{8}\,b &=& -\ 5.87778 \\
+62\,c &=& +29.76000 \\
-\tfrac{307}{8}\,d &=& -23.48550 \\
+13\,e &=& -33.50100 \\
-\tfrac{15}{8}\,f &=& \underline{+32.39250} \\
\text{Sum} &=& -\ 0.74078
\end{aligned}$$

log sum	$8.89801n$	log sum	9.50389	log sum	$9.86969n$
log 16	1.20412	log 16^2	2.40824	log 16^3	3.61236
log s	7.69389	log u	7.09565	log v	$6.25733n$
log 1	0.00000	log 2	0.30103	log 6	0.77815
$\log \frac{d'\alpha}{dt}$	$7.69389n$	$\log \frac{1}{2}\frac{d'^2\alpha}{d^2t}$	6.79462	$\log \frac{1}{6}\frac{d'^3\alpha}{dt^3}$	$5.47918n$

$$\frac{d'\alpha}{dt} = -0.0049419 \qquad \frac{1}{2}\frac{d'^2\alpha}{dt^2} = +0.00062318 \qquad \frac{1}{6}\frac{d'^3\alpha}{dt^3} = -0.000030143$$

$+\frac{137}{2}b = +\overset{s.}{6.98700}$	$+20a = -\overset{s.}{0.02000}$	$+15b = +\overset{s.}{1.530}$
$-31a = +0.03100$	$-\frac{95}{2}b = -4.84500$	$-6a = +0.006$
$-\frac{242}{3}c = -38.72000$	$+60c = +28.80000$	$-20c = -9.600$
$+\frac{107}{2}d = +32.74200$	$-\frac{85}{2}d = -26.01000$	$+15d = +9.180$
$-19e = +48.96300$	$+16e = -41.23200$	$-6e = +15.462$
$+\frac{17}{6}f = -48.94868$	$-\frac{5}{2}f = +43.19000$	$+f = -17.276$
Sum = + 1.05432	Sum = − 0.11700	Sum = − 0.698

log sum	0.02297	log sum	$9.06819n$	log sum	$9.84386n$
log 16^4	4.81648	log 16^5	6.02060	log 16^6	7.22472
log x	5.20649	log y	$3.04759n$	log z	$2.61914n$
log 24	1.38021	log 120	2.07918	log 720	2.85733
$\log \frac{1}{24}\frac{d'^4\alpha}{dt^4}$	3.82628	$\log \frac{1}{120}\frac{d'^5\alpha}{dt^5}$	$0.96841n$	$\log \frac{1}{720}\frac{d'^6\alpha}{dt^6}$	$9.76181n$

$$\frac{1}{24}\frac{d'^4\alpha}{dt^4} = +0.00000067032 \qquad \frac{1}{120}\frac{d'^5\alpha}{dt^5} = -0.00000000062985 \qquad \frac{1}{720}\frac{d'^6\alpha}{dt^6} = -0.0000000005779$$

These values of the partial differential coefficients represent exactly all the values of $Y_0 - Y_4$ given on page 267 for every year from 1875 to 1803.

The residuals are as follows:

Epoch.	t	Assumed Values of $Y_0 - Y_4$	Computed Values of $Y_0 - Y_4$	Δ	Epoch.	t	Assumed Values of $Y_0 - Y_4$	Computed Values of $Y_0 - Y_4$	Δ
		s.	s.	s.			s.	s.	s.
1867	8	−0.002	−0.002	+0.000	1803	72	− 0.207	− 0.212	+0.005
1859	16	−0.001	−0.001	+0.000	1795	80	− 2.577	− 2.579	+0.002
1851	24	+0.024	+0.024	+0.000	1787	88	− 7.703	− 7.745	+0.042
1843	32	+0.102	+0.102	+0.000	1779	96	−17.276	− 17.279	+0.003
1835	40	+0.256	+0.256	+0.000	1771	104	−33.558	− 33.690	+0.132
1827	48	+0.480	+0.480	+0.000	1763	112	−59.531	− 60.043	+0.612
1819	56	+0.681	+0.681	+0.000	1755	120	−98.449	−100.391	+1.942
1811	64	+0.612	+0.612	+0.000					

We shall find in a similar manner from the sixteen-year intervals the following values of the coefficients of t, t^2, t^3, &c., from the residuals $Y_0 - Y_4$ from 1875 to 1955, given on page 268, viz.:

Epoch.	t	$Y_0 - Y_4$
		s.
1891	16	$a = +0.002$
1907	32	$b = -0.206$
1923	48	$c = -\ 1.785$
1939	64	$d = -\ 7.991$
1955	80	$e = -25.308$

Whence by equations (64)

	Logarithms.
$\frac{d' \alpha}{d t} = +\overset{s.}{0}.0014106$	7.14941
$\frac{1}{2} \frac{d'^2 \alpha}{d t^2} = -0.000033305$	5.92251n
$\frac{1}{6} \frac{d'^3 \alpha}{d t^3} = +0.00000093590$	3.97122
$\frac{1}{24} \frac{d'^4 \alpha}{d t^4} = +0.000000097911$	2.99083
$\frac{1}{120} \frac{d'^5 \alpha}{d t^5} = -0.0000000089646$	1.95253

These values of the coefficients will reproduce all the values of $Y_0 - Y_4$ from 1875 to 1955, within the limits of the second decimal place.

As a further illustration of the degree of approximation to which the correspondence of the exact values Y_0 with the results given by equations (64) can be carried, we select the following values of $Y_0 - Y_{12}$ given on page 281, $J = \frac{d^4 \alpha}{d t^4}$ and $w = 16$.

Epoch.	t	$Y_0 - Y_{12}$
		s.
1851	24	$a = -0.004$
1827	48	$b = +0.012$
1803	72	$c = +0.106$
1779	96	$d = +0.396$
1755	120	$e = +1.796$

Whence by equations (64)

$$\frac{d' \alpha}{d t} = +\overset{s.}{0}.0057304 \qquad \frac{1}{24} \frac{d'^4 \alpha}{d t^4} = -\overset{s.}{0}.00000017733$$

$$\frac{1}{2} \frac{d'^2 \alpha}{d t^2} = -0.0051764 \qquad \frac{1}{120} \frac{d'^5 \alpha}{d t^5} = +0.00000000077027$$

$$\frac{1}{6} \frac{d'^3 \alpha}{d t^3} = +0.000015143$$

These coefficients satisfy the values of $Y_0 - Y_{12}$ given on p. 281 as follows:

Epoch.	t	Assumed Values of $Y_0 - Y_{12}$	Computed Values of $Y_0 - Y_{12}$	Δ
		s.	s.	s.
1851	24	−0.004	−0.004	+0.000
1843	32	+0.000	+0.000	+0.000
1835	40	+0.004	+0.004	+0.000
1827	48	+0.012	+0.012	+0.000
1819	56	+0.028	+0.027	+0.001
1811	64	+0.060	+0.069	−0.009
1803	72	+0.106	+0.106	+0.000
1795	80	+0.170	+0.159	+0.011
1787	88	+0.263	+0.241	+0.022
1779	96	+0.396	+0.396	+0.000
1771	104	+0.604	+0.657	−0.053
1763	112	+0.990	+1.095	−0.105
1755	120	+1.796	+1.796	+0.000

It is evident that the interval of twenty-four years is in this case too great to allow an exact reproduction of the intermediate values of $Y_0 - Y_{12}$. We employ, therefore, equations (66) with the interval $w = 20$, in which it is necessary to compute the additional values for $t = 20$, $t = 60$, and $t = 100$.

DATA FOR THE COMPUTATION OF THE COEFFICIENTS.

Epoch.	t	$Y_0 - Y_{12}$
		s
1855	20	$a = -0.002$
1835	40	$b = +0.004$
1815	60	$c = +0.043$
1795	80	$d = +0.170$
1775	100	$e = +0.480$
1755	120	$f = +1.796$

Whence by equations (66)

$$\frac{d' \alpha}{d t} = -\overset{s.}{0}.005808 \qquad \frac{1}{24} \frac{d'^4 \alpha}{d t^4} = +\overset{s.}{0}.00000050287$$

$$\frac{1}{2} \frac{d'^2 \alpha}{d t^2} = +0.00064775 \qquad \frac{1}{120} \frac{d'^5 \alpha}{d t^5} = -0.0000000043880$$

$$\frac{1}{6} \frac{d'^3 \alpha}{d t^3} = -0.000026536 \qquad \frac{1}{720} \frac{d'^6 \alpha}{d t^6} = +0.000000000014714$$

The values of $Y_0 - Y_{12}$ are now represented as follows:

Epoch.	t	Assumed Values of $Y_0 - Y_{12}$	Computed Values of $Y_0 - Y_{12}$	Δ
		s.	s.	s.
1855	20	-0.002	-0.002	$+0.000$
1851	24	-0.004	-0.004	$+0.000$
1843	32	$+0.000$	$+0.000$	$+0.000$
1835	40	$+0.004$	$+0.004$	$+0.000$
1827	48	$+0.012$	$+0.013$	-0.001
1819	56	$+0.028$	$+0.030$	-0.002
1815	60	$+0.043$	$+0.043$	$+0.000$
1811	64	$+0.060$	$+0.057$	$+0.003$
1803	72	$+0.106$	$+0.088$	$+0.018$
1795	80	$+0.170$	$+0.170$	$+0.000$
1787	88	$+0.263$	$+0.256$	$+0.007$
1779	96	$+0.396$	$+0.384$	$+0.012$
1775	100	$+0.480$	$+0.480$	$+0.000$
1771	104	$+0.604$	$+0.611$	-0.007
1763	112	$+0.990$	$+1.030$	-0.040
1755	120	$+1.796$	$+1.796$	$+0.000$

In the choice of the interval w, it will be safe to assume any value not exceeding 15 when equations (64) and (66) are employed. When the interval does not exceed ten years, the correspondence will in any case be exact for the intermediate dates.

The following residuals, $Y_0 - Y_3$, will indicate how far beyond the last value of the series the correspondence with the exact values may continue. They were computed from equations (66), using slightly different elements from those thus far employed, in which $w = 10$. The correspondence for sixty years was found to be exact in every case. After this time, the assumed and the computed values were found to be as follows:

Epoch.	t	Assumed Values of $Y_0 - Y_3$	Computed Values of $Y_0 - Y_3$	Δ
		s.	s.	s.
1810	65	$+61.27$	$+61.26$	$+0.01$
1805	70	$+82.02$	$+81.98$	$+0.04$
1800	75	$+107.38$	$+107.32$	$+0.06$
1795	80	$+137.88$	$+137.74$	$+0.14$
1790	85	$+174.06$	$+173.75$	$+0.31$
1785	90	$+216.44$	$+215.81$	$+0.63$
1780	95	$+265.51$	$+264.36$	$+1.15$
1775	100	$+321.75$	$+319.81$	$+1.94$

It is obvious from this example, that there is no decided gain in the selection of residuals beyond the order $Y_0 - Y_3$ for the application of this method, unless the final values $Y_0 - Y_{12}$ are chosen. It will be seen that at the end of 15 years after the last date of the series the error amounts to only $0^s.06$. The computation will be expeditiously performed by making $w = 10$, and by changing the equinox at intervals of sixty years.

Collecting our results, we have, from pages 260, 261, and page 295, for any value of $+t$ between 1875 and 1955:

$$\begin{aligned} \alpha = \alpha_0 &+ [+\overset{s.}{73}.514324 + \overset{s.}{0}.0014106]\, t \\ &+ [-\ 0.15118944 - 0.000033305]\, t^2 \\ &+ [-\ 0.000339577 + 0.00000093590]\, t^3 \\ &+ [+\ 0.0000034726 - 0.0000000977911]\, t^4 \\ &\qquad\qquad\qquad + [+\ 0.0000000089646]\, t^5 \end{aligned}$$

In like manner, we have from pages 260–264, and from page 296, for any value of $-t$ between 1875 and 1755, t being taken with the position sign in the computation of the secondary terms:

$$\begin{aligned} \alpha = \alpha_0 &+ [+\overset{s.}{73}.514324 + \overset{s.}{0}.005808]\, t \\ &+ [-\ 0.15118944 + 0.00064775]\, t^2 \\ &+ [-\ 0.000339577 + 0.000026536]\, t^3 \\ &+ [+\ 0.0000034726 + 0.00000050287]\, t^4 \\ &+ [-\ 0.000000005169 + 0.0000000043880]\, t^5 \\ &+ [-\ 0.00000000005554 + 0.000000000014714]\, t^6 \\ &\quad + 0.0000000000003173\, t^7 \\ &\quad + 0.000000000000000163\, t^8 \\ &\quad - 0.0000000000000000845\, t^9 \\ &\quad + 0.00000000000000000259\, t^{10} \\ &\quad + 0.000000000000000000119\, t^{11} \\ &\quad - 0.0000000000000000000000080\, t^{12} \end{aligned}$$

The second part of this paper will be comprised under the following subdivisions:—

(*a*.) Treatment of the proper motion for close polar stars.

(*b*.) Yearly ephemerides of all stars within 3° of the pole, between the limits 1860 and 1885.

(*c*.) Tabular values of the terms U^{I}, U^{II}, U^{III}, U^{IV}, U^{V}, &c., carried as far as will be necessary to give the exact reduction for 40 years.

(*d*.) Tabular values of the proper motions at intervals of 8 years for close polar stars, and at intervals of 20 years for all other stars.

(*e.*) Data for the reduction of the different catalogues employed to the system of Publication XIV.

(*f.*) Tabular values of the systematic relations between the catalogue of Publication XIV. and the different catalogues compared.

(*g.*) Final catalogues of 130 stars resulting from this discussion.

(*h.*) Comparison of the final catalogue with the various catalogues from which it has been derived.

MEMOIRS

OF

THE AMERICAN ACADEMY

OF

ARTS AND SCIENCES.

MDCCLXXX.

CENTENNIAL VOLUME.

VOL. XI.—PART V.—NO. VI.

CAMBRIDGE:
JOHN WILSON AND SON.
University Press.
1887.

[Investigations on Light and Heat published with Appropriation from the Rumford Fund.]

VI.

Pritchard's Wedge Photometer.

By S. P. LANGLEY, C. A. YOUNG, and E. C. PICKERING.

Presented November 10, 1886.

The attention of astronomers has been directed to the use of a wedge of shade glass as a photometer by the publication of the Uranometria Oxoniensis. The excellent measures contained in this work of the light of the stars were made with an instrument devised by Professor Charles Pritchard. A sliding wedge of shade glass was inserted between the eye of the observer and the eye-lens of a telescope. The star to be measured was brought into the field of view, and the wedge moved until the star disappeared. A graduated scale attached to the wedge served to measure its position, and consequently the thickness of glass required to render the star invisible. In order that I might submit an instrument of this kind to a careful test, I requested Professor Pritchard to order the construction for the Observatory of Harvard College of a photometer like his, which he kindly consented to do. On receiving the instrument, it seemed best to subject it to an examination at various observatories. The neutral color of the glass is of course a matter of prime importance. To the eye this particular wedge is all that can be desired, and probably the errors from this source would not affect ordinary star measurements. A severer test is, however, required to detect small systematic errors, especially in the case of colored stars. For this purpose it is necessary to determine the absorption of each portion of the wedge for rays of various wave-lengths. The bolometer appears to be the best instrument for this purpose, and Professor Langley agreed to make the required measurements, the result of which is given below.

To determine how far the instrument is to be recommended to those undertaking photometric observations, it was desirable that it should be tried by some one skilled in the use of astronomical and physical instruments. It was also preferable that the observations should be made by some one who had not acquired special skill with any one form of stellar photometer, and thus become prejudiced in its favor. These conditions are fulfilled by Professor Young, who fortunately was willing to undertake the required examination, and who has kindly prepared the statement given below.

Some Photometric Observations with the Pritchard Wedge.

By C. A. YOUNG.

At the request of Professor Pickering, I have made a few observations with the Pritchard wedge photometer belonging to the Harvard College Observatory. I regret that unfavorable weather and other circumstances have prevented the series from being more complete. The instrument has the wedge next the eye. The eye-piece, which magnifies the star image, is a *single lens*, in the focus of which is a small diaphragm. The lowest power lens of the three provided with the instrument was always used, and the $\frac{1}{4}$-inch diaphragm. With the 23-inch telescope the magnifying power was about 300, and the field of view was about $2\frac{1}{2}'$, far too small for convenience. Great difficulty was found in keeping the eye so placed as to receive the emergent pencil, as the long, flat surface of the metal plate that protects the wedge was in the way of the nose and forehead. If the wedge, instead of being next the eye, were placed at the principal focus of the eye-piece, where micrometers are usually put, it would be much easier to use the instrument; nor do I believe that, with proper precautions, there would be any loss of accuracy. There should be also some device for automatically recording the readings without the necessity of using a light. Being without an assistant available for the purpose, I had to make and record my own readings, and, after making a reading and recording it, it was necessary to wait a considerable time until the eye had regained its sensitiveness before making a new reading. By taking the precaution to make the extinctions always with one eye (the left), and to keep that eye closed while making the reading and record with the other eye, I found it possible to reduce this waiting period somewhat, and to make and record the extinctions at the rate of about two in five minutes.

The observation of extinctions was found very trying to the eyesight, — the intent gazing into absolute darkness after a luminous point that was almost invisible, or visible only by intermittent glimpses, and the gradual pushing of the wedge until one was sure that the star at last just could *not* be seen. On two out of the four evenings the work was stopped at the end of about two hours by an attack of transient *hemiopsia*. However it may be in respect to accuracy, it is unquestionable that the observation of *extinctions* is much more wearisome and difficult than that of *equalizations*, as in the various forms of double-image photometers.

The observations were made upon six stars in the A. A. A. S. star magnitude chart of the region following γ Pegasi. They are designated by corresponding numbers in Fig. 1. On the original chart their magnitudes were given as follows, viz.: No. 1, 10th; No. 2, 11th; No. 3, 11th; No. 4, 11th; No. 5, 11th; and No. 6, 13th. Of course these magnitudes, shown by the symbols on the chart, are only intended to be roughly accurate, no gradations smaller than whole magnitudes being indicated. The points surrounded by dotted circles indicate stars not contained in the original chart, but added by the Princeton telescope. The observations were made in the following order. First, five extinctions of Nos. 1, 2, and 3, then five each of 3, 2, and 1, in reverse order; the whole thirty extinctions taking about an hour and a quarter. Then five extinctions each were made of the smaller stars, 4, 5, and 6. On the first night, however, only No. 5 was observed.

REGION FOLLOWING γ PEGASI. PHOTOMETER STARS. OCTOBER, NOVEMBER, 1886.

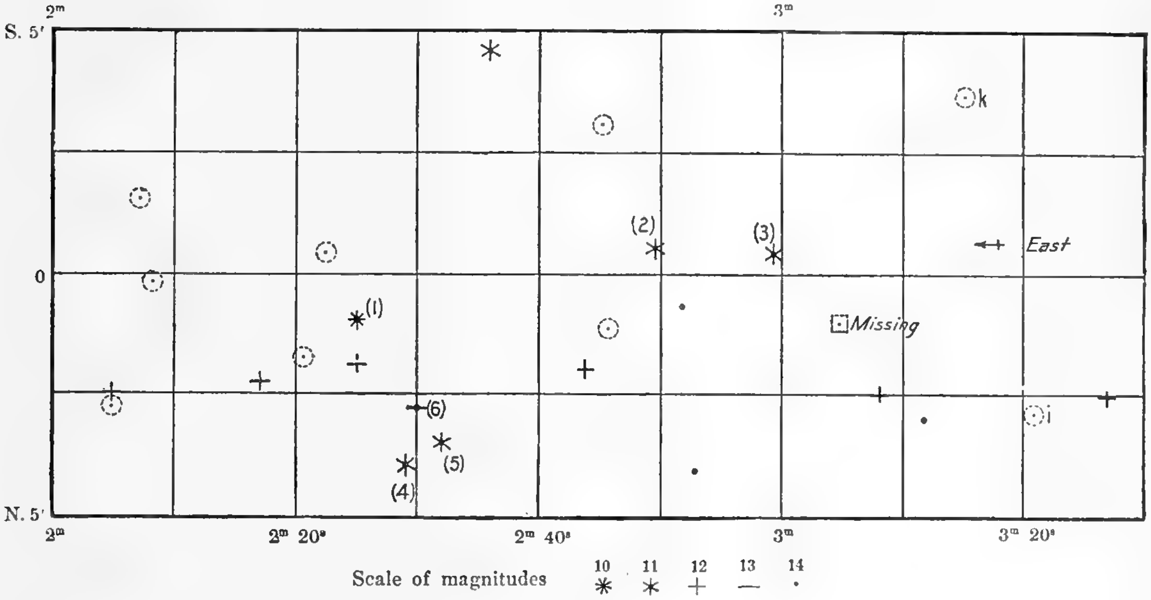


FIG. 1.

In reducing the observations, the mean of the thirty readings of the first three stars was taken, and the mean of all the readings of each of the stars was compared with this mean. In the table below, Δ_1, Δ_2, etc. are the differences between the extinction points for each star and the mean of Nos. 1, 2, and 3; the columns headed r are the differences between the individual results and the mean result for the four evenings. A plus sign in the Δ column denotes that the star was *brighter* than the mean of the 3, which mean was used as the standard. The observations were all made within 1½ hours of the meridian. November 4th was bright moonlight. There was a slight moonlight during part of the observations of November 1st, but not enough to be troublesome; the background on which the stars disappeared became perfectly black before they vanished, which was not the case on November 4th with stars 4 and 6. These were lost to the eye, while the sky background was still visible in the diaphragm hole.

	10 Readings.		10 Readings.		10 Readings.		5 Readings.		5 Readings.		5 Readings.	
	Δ_1	r_1	Δ_2	r_2	Δ_3	r_3	Δ_4	r_4	Δ_5	r_5	Δ_6	r_6
	in.		in.		in.		in.		in.		in.	
Oct. 21	+0.410	+.001	−0.373	−.100	−0.038	−.105	. . . .	. . .	−0.497	−.030	. . . .	. . .
Oct. 22	+0.341	+.068	−0.529	+.056	+0.189	+.122	−0.767	−.083	−0.469	−.002	−1.421	+.184
Nov. 1	+0.484	+.075	−0.535	+.062	+0.062	−.005	−0.824	−.026	−0.322	+.145	−1.526	+.079
Nov. 4	+0.401	−.008	−0.454	−.019	+0.053	−.014	−0.960	+.110	−0.580	−.113	−1.868	−.263
	+0.409	±.053	−0.473	±.059	+0.067	±.062	−0.850	±.073	−0.467	±.072	−1.605	±.142

For some not very obvious reason, the extinction mean of the three stars varied very much on the four nights. It was respectively (in wedge-readings) 2.051, 2.113, 2.326, and 2.494 inches. It looks very much as if the eye, after practice, became able to follow the star farther before extinction.

For the first three stars the *average* deviation of the determination for each night from the mean of the four nights is ±0.062 in. of the wedge, indicating a *probable* error for one night's work of ±0.054 in., and a probable error of half that amount for the determination by the four nights' observations. Assuming from page 323 that 0.7 in. corresponds to one magnitude, the probable error of the finally determined difference of magnitude between the assumed standard (mean of Nos. 1, 2, and 3) and either of the first three stars is ±0.04 of a magnitude. For star No. 5 (read only five times each night instead of ten), it is about ±0.05 of a magnitude; the *single-night* error is about the same for No. 4, but having been observed only on three nights the final error is correspondingly larger, — about ±0.06 m. The probable error for No. 6 is nearly twice as great; it was obviously too faint to admit of a good determination by the apparatus used.

Measurements of the Transmission of the Pritchard Wedge.

BY S. P. LANGLEY.

THE recent discussions concerning the use of the Pritchard wedge may give interest to the following description of a study of it made at the suggestion of Professor E. C. Pickering, at Allegheny, by means of the bolometer, in July, 1886.

The wedge experimented upon is graduated from 0 to 6.6 inches, and we selected for measurements of absorption the points 0.3, 1.8, 3.3 (middle), 4.8, and 6.3 inches It is obvious that the increments of the thickness between these points are equal. The measurements are made by sending a horizontal beam from the siderostat through the position occupied by the wedge, W (Figs. 2 and 3), immediately behind which is a micrometer slit, S (whose length is usually kept slightly less than the height of the wedge), with doubly moving jaws set to two millimeters' aperture, the direct beam first being allowed to pass through the slit before the wedge is put in place ("*no wedge*"), and then the wedge being introduced and slid successively into the positions 0.3, 1.8, 3.3, etc.

As all the measures are taken by means of the bolometer, it will be well to precede them by some examples of the degree of accuracy obtainable by it. The probable error of a *single* measurement by the bolometer on any constant source of moderate radiant heat is but a fraction of one per cent.

An absolutely constant source is unattainable, but we give as an illustration ten consecutive readings made in connection with the following experiments, and with the same bolometer (No. 1), on a slowly-cooling Leslie cube. The unit of deflection is a millimeter on the cylindrical scale of the galvanometer.*

	DEFLECTION. (SOURCE OF HEAT, LESLIE CUBE.)
	356
	355
	354
	355
	355
	354
	354
	353
	353
	352
Mean	354.1 ± 0.3

---

* This part of the apparatus is more particularly described in an article "On hitherto Unmeasured Wave-Lengths," in the American Journal of Science for August, 1886.

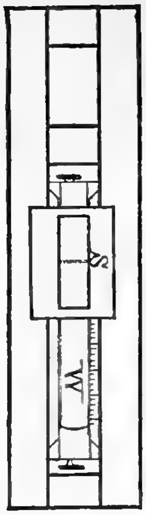


Fig. 2.

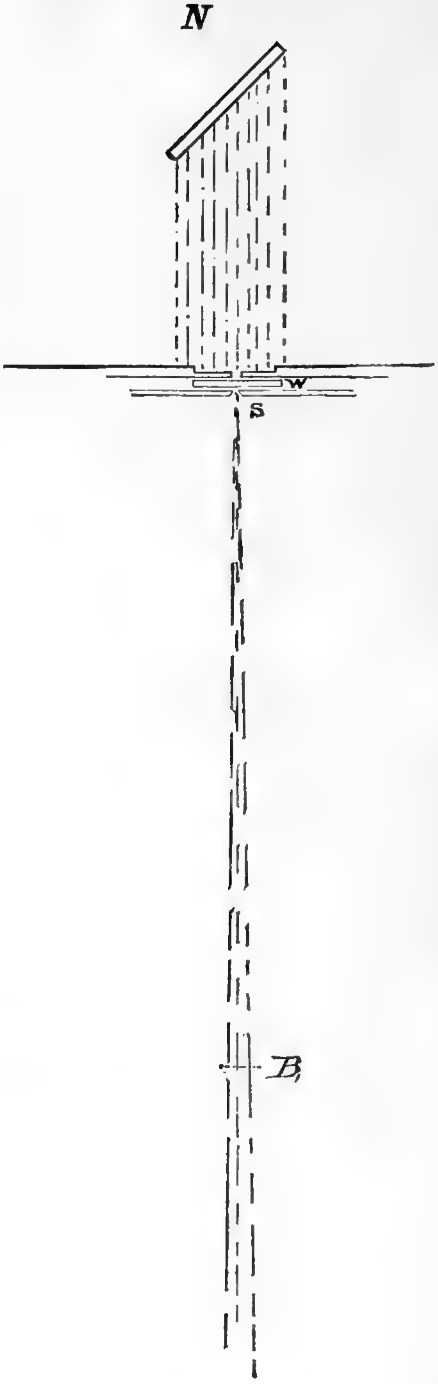


Fig. 3.

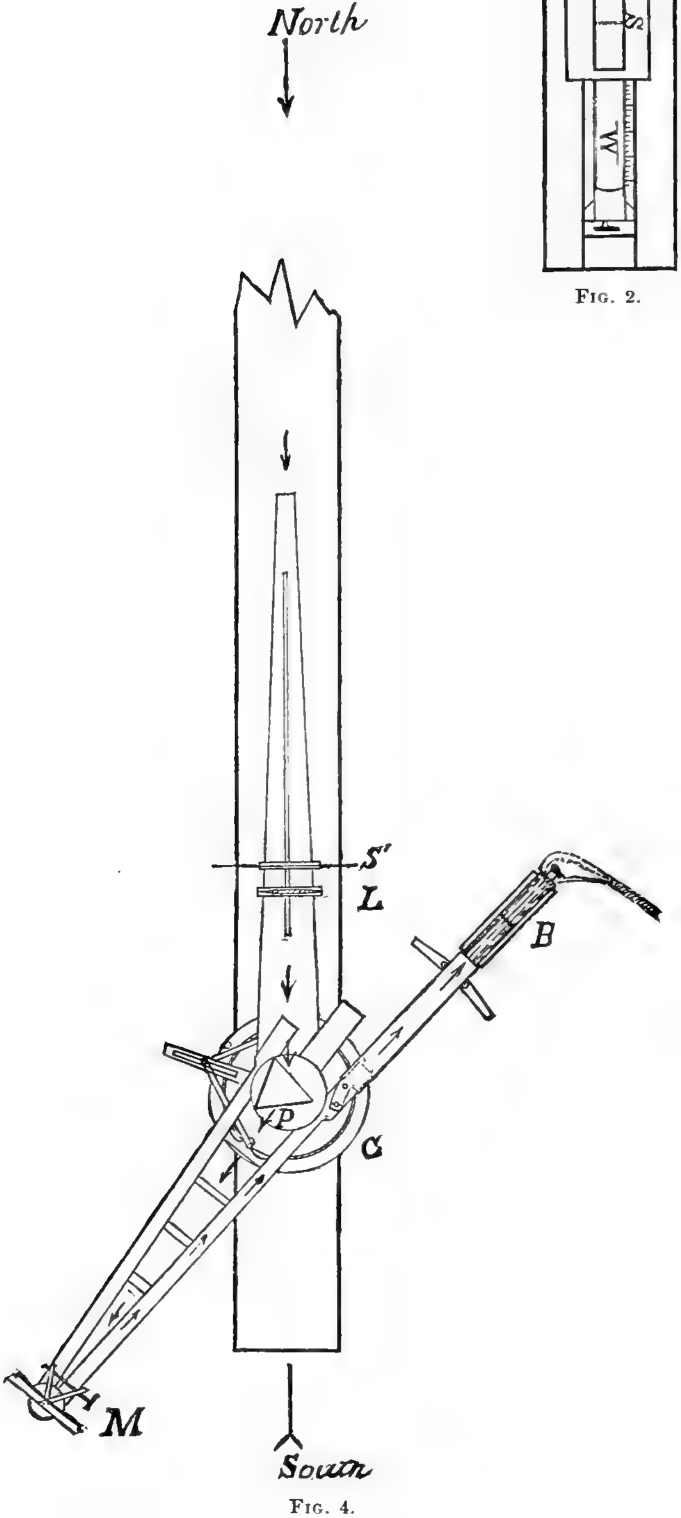


Fig. 4.

Here the probable error of the mean is $\frac{3}{10}$ of one division, or rather less than $\frac{1}{10}$ of one per cent of the whole. The probable error of a single observation is about $\frac{8}{10}$ of one division, or rather less than $\frac{1}{4}$ of one per cent of the whole. Even in this case, however, the probable error is compounded of that due to the instrument and that due to the changing temperature of the source.

If, however, we measure the solar heat, the result is less favorable; for, as I have elsewhere remarked, there is *always* found an incessant fluctuation of the heat transmission from minute to minute under an optically clear sky, or, in other words, the bolometer constantly perceives haze and mist which the eye does not.

The same day on which the above Leslie cube readings were taken, presented to the eye a fair, blue sky, with some cumulous clouds. Except for the passage of a cloud between the ninth and tenth reading, in the following series of twenty readings there was no interruption. The sky was watched critically, and even to a practised eye it appeared as clear at one time as at another. The conditions are the same, except that a shunt was introduced in the solar observations, so that the image should not be sent off the scale by the greater heat.

DEFLECTION.

(SOURCE OF HEAT, SUN, IN OPTICALLY CLEAR SKY.)

	Time 11 h.
	434
	440
	455
	468
	464
	468
	479
	475
	476
Cloud	. . . .
	421
	407
	471
	474
	447
	456
	468
	468
	475
	441
	449
Mean	456.8 ± 3.1

Here the probable error of the mean is 3.1 div., but that of a *single* observation is 13.9 div., or three per cent of the whole. This increased error is due almost wholly to the incessant variations of diathermancy of the air, and, as it will be seen by what has preceded, it is at least twelve times the proper instrumental error. With the aid of the foregoing observations, the reader will have a clearer apprehension of the trustworthiness of the means used in the following determinations.

Two kinds of measure are taken. The first is of the transmission of the total solar radiation; and in this a bolometer of 1 mm. aperture is placed directly in the path of the beam at 5 meters from the slit.

In the second, which is for the purpose of studying the absorption spectrum of the wedge, the beam after passing through the wedge and slit is rendered parallel by a horizontal collimator, L (Fig. 4), of 7.5 meters' focus, whence the rays fall on a large flint prism, P, to form a heat spectrum, which is received by a concave mirror, M, of 1.5 meters' focal length, and focused on the 1 mm. bolometer B, which is now attached to the bolometer spectroscope. The light from the siderostat mirror N is kept accurately adjusted at the centre of the screen S′ placed before the lens L. The deviations correspond to the wave-lengths $0^{\mu}.4$, $0^{\mu}.5$, $0^{\mu}.6$, $0^{\mu}.7$, and $1^{\mu}.0$, the last being invisible.* Whichever kind of measure we take, it is plain that we are in effect working through four successive equal increments of the glass from $0^{\mu}.3$ to $6^{\mu}.6$, and we may as a matter of convenience call each of these increments unity.

In the prismatic observations a difficulty arises from the great range. The scale of the galvanometer is divided into 1,000 equal parts, of which the central 500 are alone ordinarily used; but the range here, from the small heat in the violet ray ($0^{\mu}.4$), passing through the thickest part of the wedge, to the great heat in the red ray ($0^{\mu}.7$), passing through the thinnest part of it, is much over 10,000 to 1. Such differences, it will be understood, only present themselves in the prismatic investigation; but on account of them we have been obliged here to narrow the slit in some cases for the full beam to one half its normal aperture, and to reduce the values thus obtained to what they would have been with the 2 mm. slit usually employed. The values thus obtained are overscored thus: $\overline{100}$.

---

* μ = 0.001 mm. = 10,000 of Angstrom's scale.

OBSERVATIONS.

We begin by the first kind of observations, — those made in the path of the direct beam, — by measuring the transmission of the total beam at the five points mentioned, going through the wedge from thin end to thick, and then repeating the observation from thick end to thin, so as to eliminate the effect of any progressive change which may be taking place simultaneously outside in the atmospheric absorption. A set of two measures on each point constitutes a series. Each series is complete in itself, and hence (in this first class of observation) it is immaterial if, owing to changes in the sky, the absolute deflections in two series differ.

Nine such series are here given, obtained on two days of excellent sky.

TABLE I.

TIME 10 A.M. TO 12.20 P.M.

No Wedge.	Wedge at 0.3 in.	Wedge at 1.8 in.	Wedge at 3.3 in.	Wedge at 4.8 in.	Wedge at 6.3 in.	
→ 669	296	133	76.7	53.2	38.8	Series 1
← 680	294	138	78.3	51.7	38.0	
→ 678	292	148	82.1	53.4	38.2	Series 2
← 666	298	139	82.0	55.5	38.8	
→ 674	288	136	78.4	52.2	37.2	Series 3
← 613	267	131	76.9	51.6	38.5	
→ 659	282	135	79.0	50.9	37.1	Series 4
← 651	284	136	76.8	50.0	38.6	
Mean (*a*) 661 ± 5.1	288 ± 2.5	137 ± 1.2	78.8 ± 0.5	52.3 ± 0.4	38.2 ± 0.2	
(*b*) 1000	435.0	207.3	119.2	79.1	57.8	
(*c*) . . .	. . .	0.477	0.576	0.664	0.731	

(*a*) are the actual mean deflections observed on the galvanometer, in units of one millimeter.

(*b*) are the corresponding proportional value of the original beam.

(*c*) are quotients obtained by dividing the number in (*b*), giving absorption at each thickness of the wedge, by the preceding, thus: $\frac{207.3}{435.0} = \frac{477}{1000}$, $\frac{119.2}{207.3} = \frac{576}{1000}$, etc.

EXTRACT FROM ORIGINAL RECORD.

Station, Allegheny.
Date, August 2, 1886.
Temperature of Apparatus = 24° C. at 10 A.M.
State of Sky, Good blue with a very few patches of cirrocumulus. Cumuli forming toward noon.
Aperture of Slit = 2 mm. (Slit 11 mm. high.)

Slit to Bolometer = 5 m.
Galvanometer, No. 3 (damping magnet at 70 cm.).
Time of a single Vibration, 14 seconds.
Bolometer, No. 16 (1 mm. aperture).
Current of Battery = 0.039 Ampère.
Reader at Wedge, J. P.
" *Galvanometer*, F. W. V.
Watcher for Clouds, C.
Object = measurement of transmission of Pritchard wedge for total solar beam.

If there is no selective absorption, those numbers in the line (*b*) which express the absorption for thicknesses of the wedge differing by equal increments should be in geometrical progression, and the numbers in the line (*c*) should represent the constant common ratio. These last, on the contrary, increase progressively and systematically, and the same evidence of selective absorption is derived from those on the following day, August 3, 1886, when they were continued. The only conditions which had changed were:

Temperature of Apparatus, 20°.2 C. at 10.45 A.M.
State of Sky, excellent blue with occasional cumuli.
Time = 9.20 to 10.40 A.M.

TABLE II.

TIME = 9.20 TO 10.40 A.M.

No. Wedge.	Wedge at 0.3 in.	Wedge at 0.8 in.	Wedge at 3.3 in.	Wedge at 4.8 in.	Wedge at 6.3 in.	
758	336	154	82.6	55.4	39.8	Series 1
761	322	145	82.3	54.6	40.3	
757	304	140	77.2	53.4	39.0	Series 2
747	308	141	82.2	53.0	39.5	
761	311	147	82.3	56.7	41.7	Series 3
765	319	148	84.8	56.9	41.2	
763	326	149	85.2	57.7	41.9	Series 4
739	323	148	86.5	57.8	41.2	
744	328	148	85.4	56.3	42.2	Series 5
767	325	151	85.4	57.0	41.8	
Mean (*a*) 756 ± 2	320 ± 2	147 ± 1	83.4 ± 5	55.9 ± 0.4	40.9 ± 0.2	
(*b*) 1000	423.4	194.5	110.3	73.9	54.1	
(*c*) . . .	. . .	0.459	0.567	0.670	0.732	

It is obvious from a comparison of the numbers (*c*) in this table with those in Table I. that there is a very close agreement between the results of the two days, and that the variations in the transmissibility for a unit thickness are dependent on the numbers of unit thickness observed which are systematic and not accidental. To make this fact still more evident, we add in Table II *a*. the results of the nine preceding series, reduced to a uniform quantity of heat, that is, with the varied atmospheric absorption, etc. between the series eliminated.

TABLE II *a*.

No Wedge.	Wedge at 0.3 in.	Wedge at 1.8 in.	Wedge at 3.3 in.	Wedge at 4.8 in.	Wedge at 6.3 in.
1000	437.4	200.9	114.9	77.8	56.9
1000	439.0	213.5	122.2	81.1	57.3
1000	431.3	207.5	120.7	80.7	58.9
1000	432.1	206.9	118.9	77.1	57.9
1000	433.2	196.8	108.6	72.4	52.8
1000	406.9	186.8	106.0	70.7	52.3
1000	412.8	193.3	109.6	74.4	54.4
1000	432.1	197.7	114.4	77.0	55.4
1000	432.2	197.9	113.1	75.1	55.6
Means 1000	428.6 ± 2.5	200.1 ± 1.9	114.3 ± 1.3	76.3 ± 0.8	55.7 ± 0.5

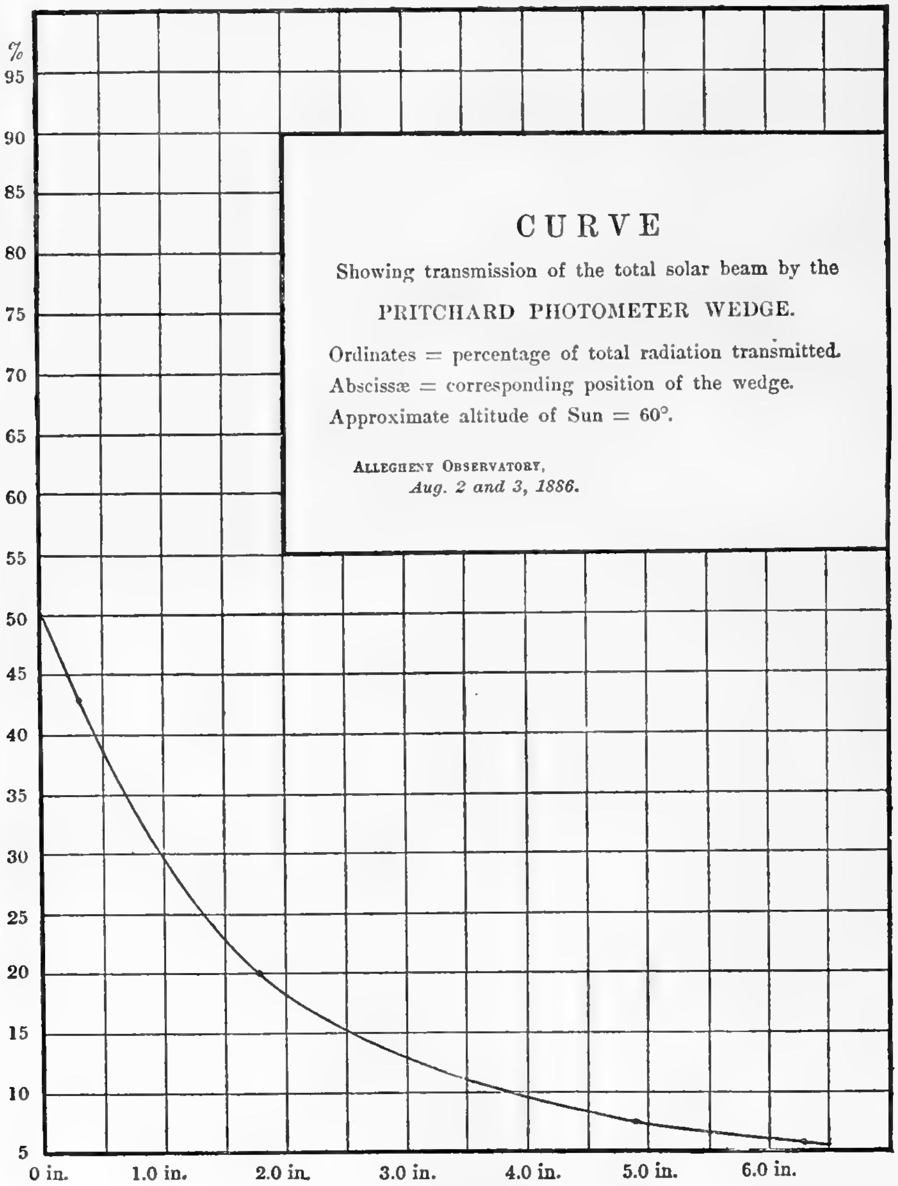
The above are the measurements of transmission of the total solar beam by the Pritchard wedge, each series being reduced separately.

Taking the mean of all the observations in Tables I. and II., we have for the final values:

No Wedge.	Wedge at 0.3 in.	Wedge at 1.8 in.	Wedge at 3.3 in.	Wedge at 4.8 in.	Wedge at 6.3 in.
(*a*) 714	305.7	142.6	81.4	54.3	39.7
(*b*) 1000	428.2	199.7	114.0	76.1	55.6
(*c*) . . .	. . .	0.467	0.570	0.668	0.731

It will be observed that the probable errors above given represent, not only those peculiar to the apparatus, but, what is much more important, the effect of all changes in the sky during some hours' observation. If each series were separately reduced to the form (*b*), the probable error of the mean would be much less.

It is of course admitted that if through any unit stratum of a homogeneous absorbent solid there pass a homogeneous ray of which n parts are transmitted, through the second equal stratum n^2 parts will be transmitted, and through n such strata n^n parts, and that the same result will follow with any ray if there be not selective absorption.



CURVE

Showing transmission of the total solar beam by the

PRITCHARD PHOTOMETER WEDGE.

Ordinates = percentage of total radiation transmitted.
Abscissæ = corresponding position of the wedge.
Approximate altitude of Sun = 60°.

ALLEGHENY OBSERVATORY,
Aug. 2 and 3, 1886.

FIG. 5.

As the result of these measures, we have then, we repeat, both in the tables for each day and in the final values, numbers in a and b which should—if the wedge be of uniform substance and figure, and apart from the consideration of reflection, etc.—increase in geometrical progression for equal increments of thickness, if there is no selective absorption in the wedge. That this is not so, is shown in *c*, where we find on the contrary that there is a very strongly marked progressive increase in the quotients there given. The variations of *b* are shown graphically in Fig. 5.

A yet more striking proof of the great selective absorption at least of the total *heat* is shown otherwise in line *b*, where we see that the heat transmitted through the thickest part of the wedge is hardly over $\frac{1}{20}$ that of the direct beam. We consider this in connection with the fact that the *light* here transmitted has been found by Professor Pickering to be something like $\frac{1}{1000}$ of the direct light. But though this is evidence of great selective absorption of heat, taking all kinds indiscriminately, it may still be quite possible that this absorption exists chiefly in the invisible, lower part of the spectrum, — that is, in the infra-red, — and that the wedge is sensibly non-selective in the visible part.

To determine this distinct absorption in the visible part, we have the prismatic measures, of which there are four or five incomplete series, obtained on three different occasions. To each of these we have also added a set of measures just *below* the visible part (at 1^{μ}) to make the tendency more evident.*

Extract from Original Record.

Station, Allegheny.
Date, July 27, 1886.
Temperature of Apparatus = 26° C.
State of Sky, milky blue.
Aperture of Slit = 2 mm. (Height of wedge was but 0.59, that of slit used to-day, but no heat entered in any case except through wedge save when that was away altogether. Deflections with wedge away are reduced by multiplying by the factor 0.59.)
Prism used, Hilger No. 3. (A very large Flint prism.)
Spectrum thrown west.
Galvanometer, No. 3.
Time of single Vibration, 9 sec.
Bolometer, No. 16 (1 mm. aperture).

---

* It may possibly not be superfluous to recall to the reader, that, while the wave-length $0^{\mu}.4$ in the following tables corresponds nearly to the extreme violet, that at $0^{\mu}.7$ to the extreme red, and the visible spectrum or "light heat" lies almost wholly between these points, the greater part of the whole solar energy is found in wave-lengths greater than $0^{\mu}.7$ in the form of *invisible* radiation or "dark heat." (The radiation in wave-lengths beyond the violet is here quite negligible.) As we are not particularly concerned here with this "dark heat," we have confined our measures to points between 0.4 and 0.7 inclusive (light heat), except one set at 1^{μ} (dark heat), just below the red, which we have added to make more evident the tendency of the absorption to *increase* as the wave-lengths increase, though for one and the same unit thickness. If there be any linear selective absorption in the wedge, it is not evident in such observations as these. Of course throughout this investigation the assent of the reader is assumed to the recognized principle that a change in the rate of absorption of the heat in any ray implies a like change in the rate of absorption of light in the same ray.

Setting on Slit (before mounting prism) 0° 0′ 0″.
" D_2* (after " ") 315° 47′ 30″.
Current of Battery = 0.040 Ampère.
Reader (alternately) *at Circle and Wedge,* J. P.
" *at Galvanometer,* F. W. V.
Object = measurement of transmission of Pritchard wedge for different parts of the spectrum.
Time 11.30 A.M. to 2.05 P.M.

TABLE III.

λ	No Wedge.	Wedge at 0.3 in.	Wedge at 1.8 in.	Wedge at 3.3 in.	Wedge at 4 8 in.	Wedge at 6.3 in.
⟶ $0^{\mu}.4$	$\overline{40.7}$	9.1	1.5	. . .	. . .	. . .
⟵ (Dev. 46° 40′)	$\overline{35.7}$	9.5	1.3	. . .	. . .	. . .
Mean of Series 1	$\overline{38.2}$	9.3	1.4	. . .	. . .	. . .
⟶ $0^{\mu}.5$	$\overline{174.0}$	47.5	7.4	1.2	. . .	. . .
⟵ (Dev. 44° 58′)	$\overline{174.0}$	50.5	7.1	1.1	. . .	. . .
Mean of Series 2	$\overline{174.0}$	49.0	7.3	1.2	. . .	. . .
⟶ $0^{\mu}.6$	$\overline{347.0}$	99.0	12.9	3.3	0.7	. . .
⟵ (Dev. 44° 7′)	$\overline{338.0}$	100.0	14.4	2.3	0.4	. . .
Mean of Series 3	$\overline{343.0}$	99.5	13.7	2.8	0.6	. . .
⟶ $0^{\mu}.7$	$\overline{520.0}$	225.0	61.4	17.3	5.3	1.1
⟵ (Dev. 43° 37′)	$\overline{533.0}$	261.0	68.0	16.0	4.9	0.7
Mean of Series 4	$\overline{527.0}$	243.0	64.7	16.7	5.1	0.9
⟶ $1^{\mu}.0$	$\overline{822.0}$	504.0	267.0	137.0	65.0	34.2
⟵ (Dev. 42° 54′)	$\overline{835.0}$	454.0	213.0	122.0	62.0	35.0
Mean of Series 5	$\overline{829.0}$	479.0	240.0	129.0	63.5	34.6

PRISMATIC OBSERVATIONS OF WEDGE TRANSMISSION OF AUGUST 9, 1886.

EXTRACT FROM ORIGINAL RECORD.

Temperature of Apparatus = 25°.3 C. at 11 A.M.
State of Sky, milky blue with cumuli.
Aperture of Slit = 2 mm. (Height of slit is to-day reduced to 11 mm., or slightly *less* than that of the wedge.)
Prism used, Hilger No. 3.
Galvanometer, No. 3 (damping magnet at 70 cm.).
Time of a single Vibration = 14 seconds.

---

* An optical setting on the sodium line D_2 is always made as a check on the accuracy of adjustment of the prismatic apparatus.

Bolometer, No. 16 (1 mm. aperture), accurately adjusted for the varying focus of each point in the spectrum.
Setting on Slit (before mounting prism) = 0° 0′ 0″.
" D_2 (after " ") = 315° 48′ 15″.
Current of Battery, 0.040 Ampère.
Reader at Circle and Wedge, J. P.
" *Galvanometer*, F. W. V.
Watcher for Clouds, C.
Object = measurement of transmission of Pritchard wedge for different parts of the spectrum.
Time, 11 A.M. to 2.15 P.M.

TABLE IV.

λ	No Wedge.	Wedge at 0.3 in.	Wedge at 1.8 in.	Wedge at 3.3 in.	Wedge at 4.8 in.	Wedge at 6.3 in.
⟶ $0^{\mu}.4$	52.0	12.7	1.9	. . .	. . .	. . .
⟵ (Dev. 46° 40′)	56.1	13.3	1.1	. . .	. . .	. . .
Mean of Series 1	54.1	13.0	1.5	. . .	. . .	. . .
⟶ $0^{\mu}.5$	267.0	68.4	9.0	1.4	. . .	. . .
⟵ Dev. (44° 58′)	244.0	65.9	9.7	1.1	. . .	. . .
Mean of Series 2	256.0	67.2	9.4	1.3	. . .	. . .
⟶ $0^{\mu}.6$	566.0	157.0	21.2	3.2	0.4	. . .
⟵ (Dev. 44° 7′)	588.0	158.0	19.4	2.4	0.2	. . .
Mean of Series 3	577.0	158.0	20.3	2.8	0.3	. . .
⟶ $0^{\mu}.7$	$\overline{799.0}$	311.0	83.5	21.5	5.1	1.0
⟵ (Dev. 43° 37′)	$\overline{733.0}$	319.0	88.0	21.8	5.1	1.4
Mean of Series 4	$\overline{766.0}$	315.0	85.8	21.7	5.1	1.2
⟶ $1^{\mu}.0$	$\overline{933.0}$	578.0	311.0	152.0	83.0	37.9
⟵ (Dev. 42° 54′)	$\overline{1014.0}$	581.0	288.0	158.0	80.5	34.9
Mean of Series 5	$\overline{974.0}$	580.0	300.0	155.0	81.8	36.4
⟶ $0^{\mu}.4$	42.9	8.6	1.5	. . .	. . .	. . .
⟵ (Dev. 46° 40′)	42.6	9.8	1.1	. . .	. . .	. . .
Mean of Series 6	42.8	9.2	1.3	. . .	. . .	. . .
$0^{\mu}.5$ $0^{\mu}.6$	} Clouds prevented the completion of these series.					
⟶ $0^{\mu}.7$	$\overline{756.0}$	299.0	78.5	19.8	5.1	1.1
⟵ (Dev. 43° 37′)	$\overline{721.0}$	286.0	79.0	21.7	5.9	1.1
Mean of Series 7	$\overline{740.0}$	293.0	78.8	20.8	5.5	1.1
⟶ $1^{\mu}.0$	$\overline{948.0}$	468.0	260.0	143.0	78.8	31.9
⟵ (Dev. 42° 54′)	$\overline{896.0}$	572.0	282.0	150.0	85.5	37.2
Mean of Series 8	923.$\overline{0}$	520.0	271.0	147.0	82.2	34.6

PRISMATIC OBSERVATIONS OF WEDGE TRANSMISSION MADE AUGUST 10, 1886.

TABLE V.

λ	No Wedge.	Wedge at 0.3 in.	Wedge at 1.8 in.	Wedge at 3.3 in.	Wedge at 4.8 in.	Wedge at 6.3 in.
⟶ $0^{\mu}.4$	35.3	10.0	1.0	. . .	. . .	. . .
⟵ (Dev. 46° 40′)	37.0	8.6	1.4	. . .	. . .	. . .
Mean of Series 1	36.2	9.3	1.2	. . .	. . .	. . .
⟶ $0^{\mu}.5$	173.0	64.5	9.2	1.3	. . .	. . .
⟵ (Dev. 44° 58′)	245.0	70.1	11.2	0.6	. . .	. . .
Mean of Series 2	209.0	67.3	10.2	1.0	. . .	. . .
⟶ $0^{\mu}.6$	482.0	132.0	19.7	2.6	. . .	. . .
⟵ (Dev. 44° 7′)	566.0	125.0	16.7	2.6	. . .	. . .
Mean of Series 3	524.0	129.0	18.2	2.6	. . .	. . .
⟶ $0^{\mu}.7$	810.0	308.0	86.3	21.7	6.4	1.7
⟵ (Dev. 43° 37′)	865.0	330.0	90.6	23.1	6.6	1.6
Mean of Series 4	838.0	319.0	88.5	22.4	6.5	1.6
⟶ $1^{\mu}.0$	1240.0	684.0	367.0	190.0	96.2	51.4
⟵ (Dev. 42° 54′)	1176.0	692.0	369.0	197.0	95.7	49.9
Mean of Series 5	1209.0	688.0	368.0	194.0	96.0	50.7
Above observations taken before 12.30 P.M.; the following, after 12.30 P.M.						
⟶ $0^{\mu}.4$	30.9	7.2	0.6	. . .	. . .	. . .
⟵ (Dev. 46° 40′)	35.9	7.8	0.6	. . .	. . .	. . .
Mean of Series 6	33.4	7.5	0.6	. . .	. . .	. . .
⟶ $0^{\mu}.5$	191.0	52.6	6.3	0.9	. . .	. . .
⟵ (Dev. 44° 58′)	208.0	55.0	7.5	1.1	. . .	. . .
Mean of Series 7	200.0	53.8	6.9	1.0	. . .	. . .
⟶ $0^{\mu}.6$	430.0	122.0	17.9	2.3	. . .	. . .
⟵ (Dev. 44° 7′)	497.0	134.0	16.5	2.7	. . .	. . .
Mean of Series 8	464.0	128.0	17.2	2.5	. . .	. . .
⟶ $0^{\mu}.7$	742.0	275.0	76.6	19.6	5.0	0.9
⟵ (Dev. 43° 37′)	762.0	279.0	76.2	19.4	5.1	1.1
Mean of Series 9	752.0	277.0	76.4	19.5	5.1	1.0
⟶ $1^{\mu}.0$	1129.0	671.0	345.0	184.0	98.6	43.8
⟵ (Dev. 42° 54′)	1121.0	682.0	353.0	187.0	95.6	44.5
Mean of Series 10	1124.0	677.0	349.0	186.0	97.1	44.2

EXTRACT FROM ORIGINAL RECORD.

Conditions the same as on the previous day, August 9, except the following: —
Temperature of Apparatus = 30 C. at 2 P.M.
State of Sky, milky blue with cumuli. Good sky between clouds.
Setting on D_2 = 315° 47′ 15″. (Slit = 0° 0′ 0″.)
Battery Current = 0.038 Ampère.
Object = repetition of measurements of wedge transmission at different points in the spectrum.
Time of first five series 10.15 A.M. to 12.30 P.M.
" last " " 12.30 P.M. to 1.45 P.M.

In our measures in the direct beam each series was complete in itself, and hence we were independent of any changes of the weather from day to day; but here, though the series as between different points of the wedge may be also complete in itself, it is not necessarily true that the comparison between different wave-lengths made on different days, though at the same point of the wedge, is to be made with equal immunity.

Owing to variations in the initial solar radiation, due to atmospheric changes and the alteration of atmospheric absorption, with the changing altitude of the sun, the foregoing series as represented by the *vertical* columns are not then so strictly comparable with each other; nor, rigorously speaking, can one day be exactly comparable with another when the progressive absorption in the spectrum is in question, rather than the rate of absorption for different parts of the wedge. The following continuous series, made when the sun's altitude above the horizon was 54°, with the wedge set at 0.3 in., will however serve to indicate the relative intensities for one position.

TABLE VI.

WEDGE AT 0.3 in.

Wave-Length (λ).	$0^{\mu}.4$	$0^{\mu}.5$	$0^{\mu}.6$	$0^{\mu}.7$	$1^{\mu}.0$
⟶	7.2	48.6	104.0	246.0	553.0
⟵	5.9	44.0	95.4	250.0	561.0
Mean Deflections	6.6	46.3	99.7	248.0	557.0

There is of course no reason why similar series should not be taken for every part of the wedge, except the inordinate time demanded in waiting for days of unexceptionable clearness; for experience seems to show that with all its drawbacks sunlight is better for this purpose than artificial light.

In order to summarize the results of the prismatic measures in Tables III., IV., and V., all the observations taken on the same successive points of the wedge, though on different days, have been grouped together in Tables VII., VIII., IX., X., and XI. The numbers in each horizontal line have been divided in turn by the first number in the line, viz. that for "*no wedge.*" Thus in Table III., $\frac{9.1}{40.7} = 224$, $\frac{47.5}{174} = 273$, the numbers which begin the horizontal line opposite "July 27" in Table VII. below.

TABLE VII.

WEDGE AT 0.3 in. SLIT = 2 mm.

$\lambda =$	$0^{\mu}.4$	$0^{\mu}.5$	$0^{\mu}.6$	$0^{\mu}.7$	$1^{\mu}.0$
July 27	224	273	286	433	613
" 27	266	289	296	490	544
August 9	244	256	277	389	620
" 9	237	270	269	435	573
" 9	200	. . .	. . .	396	494
" 9	231	. . .	. . .	397	638
August 10	283	373	274	380	552
" 10	232	286	221	382	588
" 10	233	275	284	371	594
" 10	217	264	271	366	609
Means	217 ± 5	286 ± 7	272 ± 5	404 ± 8	583 ± 9

TABLE VIII.

WEDGE AT 1.8 in. SLIT = 2 mm.

λ	$0^{\mu}.4$	$0^{\mu}.5$	$0^{\mu}.6$	$0^{\mu}.7$	$1^{\mu}.0$
July 27	37	43	37.2	118	325
" 27	36	41	42.6	128	255
August 9	37	34	37.5	105	333
" 9	20	40	33.0	120	284
" 9	35	. . .	. . .	104	274
" 9	27	. . .	. . .	110	315
August 10	28	53	40.9	107	296
" 10	36	46	29.5	105	314
" 10	18	33	41.6	103	305
" 10	17	36	33.2	100	315
Means	29.1 ± 2.0	40.8 ± 1.6	36.9 ± 1.2	110 ± 2.0	302 ± 5.0

TABLE IX.

WEDGE AT 3.3 in. SLIT = 2 mm.

$\lambda =$	$0^{\mu}.4$	$0^{\mu}.5$	$0^{\mu}.6$	$0^{\mu}.7$	$1^{\mu}.0$
July 27	. . .	6.9	9.5	33.3	167
" 27	. . .	6.3	6.8	30.0	146
August 9	. . .	5.3	5.6	26.9	163
" 9	. . .	4.5	4.0	29.7	156
" 9	. . .	. . .	. . .	26.2	151
" 9	. . .	. . .	. . .	30.1	167
August 10	. . .	7.5	5.4	26.8	153
" 10	. . .	2.4	4.6	26.7	168
" 10	. . .	4.7	5.2	26.4	163
" 10	. . .	5.1	5.4	25.5	167
Means	. . .	5.3 ± 0.4	5.8 ± 0.4	28.2 ± 0.8	160 ± 2.0

TABLE X.

WEDGE AT 4.8 in. SLIT = 2 mm.

$\lambda =$	$0^{\mu}.4$	$0^{\mu}.5$	0 .6	$0^{\mu}.7$	$1^{\mu}.0$
July 27	. . .	. . .	2.0	10.2	79.1
" 27	. . .	. . .	1.2	9.2	74.3
August 9	. . .	. . .	1.2	6.4	89.0
" 9	. . .	. . .	0.6	7.0	79.4
" 9	. . .	. . .	. .	6.7	83.1
" 9	. . .	. . .	. . .	8.2	95.4
August 10	. . .	. . .	. . .	7.9	77.6
" 10	. . .	. . .	. . .	7.6	81.4
" 10	. . .	. . .	. . .	6.7	87.3
" 10	. . .	. . .	. . .	6.7	85.4
Means	. . .	. . .	1.3 ± 0.2	7.7 ± 0.3	83.2 ± 1.4

It is not to be understood from Table XI. and others, that no sensible heat of the shorter wave-lengths is transmitted through the thicker parts of the wedge. We do not here cite such observations where any have been made, because for greater security no conclusions have been founded on the minute amounts there noted, which are liable to relatively large errors of observation.

TABLE XI.

WEDGE AT 6.3 in. SLIT = 2 mm.

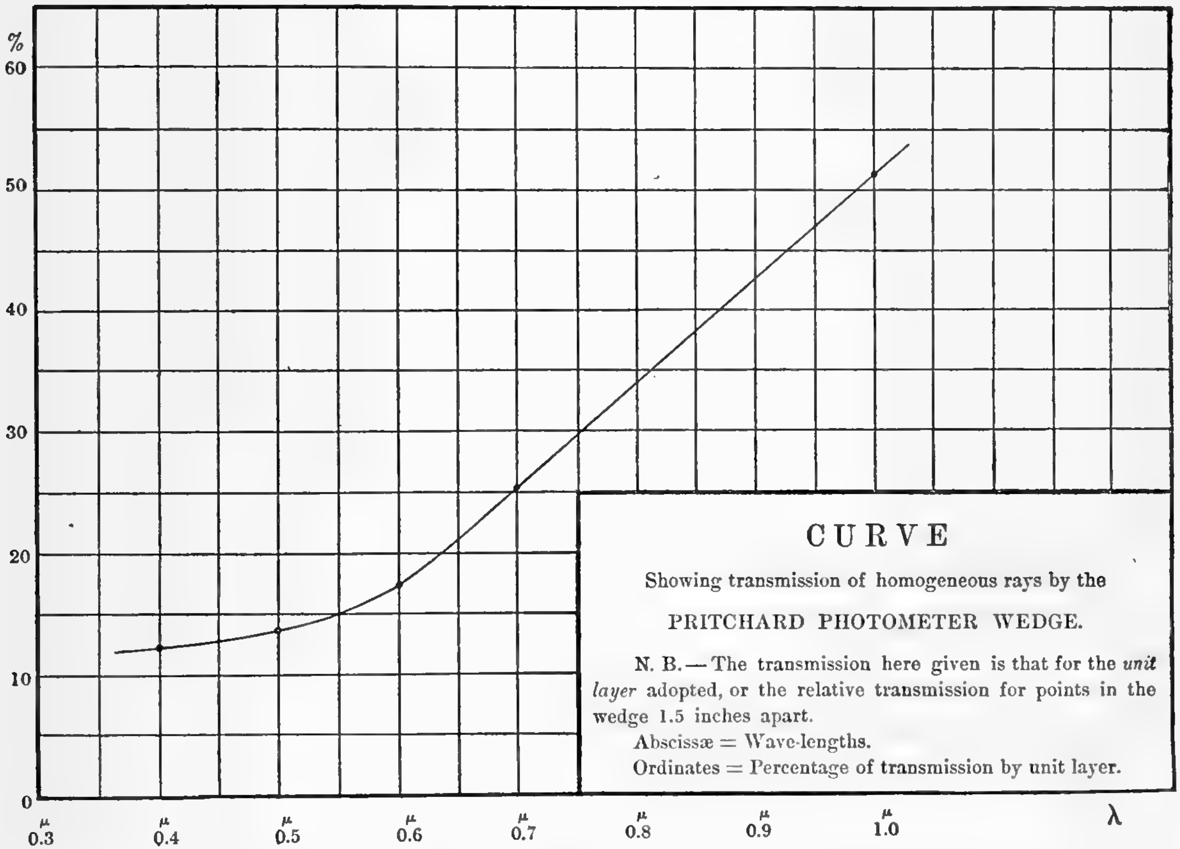
λ =	$0^{\mu}.4$	$0^{\mu}.5$	$0^{\mu}.6$	$0^{\mu}.7$	$1^{\mu}.0$
July 27	. . .	. . .	. . .	2.1	41.6
" 27	. . .	. . .	. . .	1.3	41.9
August 9	. . .	. . .	. . .	1.3	40.6
" 9	. . .	. . .	. . .	1.8	34.4
" 9	. . .	. . .	. . .	1.5	33.7
" 9	. . .	. . .	. . .	1.5	41.5
August 10	. . .	. . .	. . .	2.1	41.5
" 10	. . .	. . .	. . .	1.8	42.4
" 10	. . .	. . .	. . .	1.2	38.8
" 10	. . .	. . .	. . .	1.4	39.7
Means	. . .	. . .	. . .	1.6 ± 0.1	39.6 ± 0.7

TABLE XII.

SUMMARY OF TRANSMISSION BY PRITCHARD WEDGE FOR DIFFERENT WAVE-LENGTHS.

λ		No Wedge.	Wedge 0.3 in.	Ratio.	Wedge 1.8 in.	Ratio.	Wedge 3.3 in.	Ratio.	Wedge 4.8 in.	Ratio.	Wedge 6.3 in.
$\overset{\mu}{0}.4$	(*b*)	1000	237		29.1						
	(*c*)			0.123							
0.5	(*b*)	1000	286		40.8		5.3				
	(*c*)			0.143		0.130					
0.6	(*b*)	1000	272		36.9		5.8		1.3		
	(*c*)			0.136		0.157		0.224			
0.7	(*b*)	1000	404		110.0		28.2		7.7		1.6
	(*c*)			0.272		0.256		0.273		0.208	
1.0	(*b*)	1000	583		302.0		160.0		83.2		39.6
	(*c*)			0.518		0.530		0.520		0.476	
For λ =		$0^{\mu}.4$		$0^{\mu}.5$		$0^{\mu}.6$		$0^{\mu}.7$		$1^{\mu}.0$	
Mean Value of (*c*) =		0.123		0.137		0.172		0.252		0.511	

(*c*) may be considered in the case of a *homogeneous* ray as the *constant of transmission* for a unit thickness of the absorbing material. As the writer has elsewhere shown, it is not only *not* a constant for non-homogeneous rays, but for these latter (though still reckoned for a unit thickness) it increases as the thickness from which it is determined increases. These variations are shown in Fig. 6.



CURVE

Showing transmission of homogeneous rays by the

PRITCHARD PHOTOMETER WEDGE.

N. B.—The transmission here given is that for the *unit layer* adopted, or the relative transmission for points in the wedge 1.5 inches apart.

Abscissæ = Wave-lengths.

Ordinates = Percentage of transmission by unit layer.

FIG. 6.

In these prismatic measures the light is nearly homogeneous, and here it will be seen, by considering the ratios in the horizontal line corresponding to any single wave-length, that the ratios are constant for each ray, except for the relatively considerable errors of observation where the heat is feeble, and for the variations due to fluctuations in the original solar radiation, which may be large even with the clearest sky;* but as we go from one ray to another the ratios differ, and this difference grows very marked as we approach the red end at $0^{\mu}.7$.

* That the irregularities due to variations in the solar beam itself are relatively very much greater than those proceeding from purely instrumental causes, may also be inferred from the probable errors attached to the mean deflections of Tables I. and II; since, if these probable errors are expressed as percentages of the corresponding deflections, it will be seen that they are but slightly greater for the small deflections than they are for the large ones.

The lower line, "Mean Value of (c)," exhibits in the constant increment an interesting proof of the correctness of a theory elsewhere applied to the results of atmospheric absorption, and these prismatic observations then, on the whole, while extending and elucidating those in the direct beam, are in strict accordance with them.

CONCLUSION.

It appears from all the preceding observations, and from the established principle that changes in the thermal and optical effects are proportional in any one ray, that there is a selective absorption of light throughout the wedge, even in the visible rays; feeble in the more luminous portion of the spectrum, but of such a character that, broadly speaking, the transmissibility always increases from the violet towards the red. That it increases, and very greatly, beyond the red, is shown clearly by the additional measures we have given at $1^{\mu}.0$ in the infra-red spectrum.

Though the eye is incomparably more sensitive than the bolometer, the latter is probably able to discriminate much smaller differences quantitatively. It is therefore possible that the selective absorption so apparent to the bolometer even in the luminous spectrum may not be easily sensible ocularly, particularly as this absorption is seen to be less in the portions which are most effective in vision, such as the yellow, than in the red.

These observations, then, demonstrate that selective absorption of a quite definite character and amount exists in the submitted example of the Pritchard wedge, even in the visible rays; but they are not to be understood as necessarily proving that it does so in any degree very prejudicial to the special object of the instrument.

S. P. LANGLEY,
Director of the Allegheny Observatory.

AUGUST, *1886.*

The unexpected character of the results obtained by Professor Langley, and the importance of the conclusions to be derived from them, render it desirable that they should be checked by some wholly independent method. The wedge to the eye is of a nearly perfect neutral tint, and might be expected to transmit equally rays of all wave-lengths. The bolometer, however, shows that the variation is very great even in the visible spectrum. The proportion transmitted corresponding to a length of $1\frac{1}{2}$ inches, is 0.137 for blue light, $\lambda = 0.5$, and 0.252 for red light, $\lambda = 0.7$. This quantity corresponds to a difference of 0.44 of a magnitude per inch in the constant of the wedge if used to measure a star emitting rays composed entirely of these wave-lengths. As might be expected, when the invisible rays are included, the effect is still more marked. The portion of the total energy transmitted by the thick end of the wedge, as determined by the bolometer, is fifty times as great as the corresponding fraction of the visible light.

A series of photometric measurements were made of the wedge at the Harvard College Observatory. A photometer was used in which two portions of the same beam of light could be compared by a Nicol and double-image prism. The measures were made after one of these portions had passed through the wedge at a given distance from its end. If we employ the term *absorption* to denote the numerical increase of stellar magnitude effected by the action of the wedge, these observations could be represented by the formula $m = 0.6 + 1.3\,n$, in which m denotes the absorption, and n the reading of the scale corresponding to the part of the wedge employed in the observation. This gives, for the absorption of the point marked zero, 0.6, or the quantity whose logarithm is 0.24. In like manner the absorption for each inch in length is 1.3 magn., corresponding to the logarithm 0.52. This agrees closely with 0.51, the value found by Professor Langley for the yellow ray, $\lambda = 0.6$. The photometric measures described above failed to show the gradual diminution in the coefficient of absorption as the thickness increased. In fact, the deviation appears to be in the opposite direction. Perhaps this is due to light reflected from the rear surface of the glass, or other sources of error. As the light transmitted by the thick end of the wedge is only about one five-thousandth of the total light, a slight error in its measurement would be sufficient to produce this effect.

Another determination of the absorption of the wedge was made by photographing the solar spectrum through it. An exposure of 61 minutes gave a good photograph of the spectrum of the light of the sky when passing through the part of the wedge 3.5 inches from its end. Several exposures of from 5 to 30 seconds were made on the same plate after removing the wedge. From about $\lambda = 0.5$ where the photographic image began, to $\lambda = 0.43$, the spectrum with the wedge had nearly the same intensity as the spectrum without the wedge, having an exposure of 10 seconds. Photographic action appears to be nearly independent of the time during which a given amount of energy is expended upon a plate. In other words, the light required to produce a given image is nearly inversely proportional to the exposure. The logarithm of the proportion of the light transmitted by the wedge would therefore be 7.44. Allowing 0.24 for the absorption of the wedge at the point marked zero, as found above, we have 7.78 for the reduction caused by 3.5 inches. This gives for the absorption per inch the ratio whose logarithm is 0.7, or a somewhat greater value than that found by Professor Langley. The photograph shows that the intensity of the spectrum transmitted by the wedge falls off rapidly beyond $\lambda = 0.41$, the photographic image becoming entirely invisible where $\lambda = 0.40$. The H and K lines cannot be detected in this spectrum, although readily seen in the other images. The opacity of the wedge increases rapidly as the wave-length diminishes, as shown by the bolometer. A second photograph was taken of the light transmitted at the point marked 5.5 inches, and confirmed the above results. The exposure lasted for nearly an entire day, and the brightest part was about equal to a spectrum obtained in 10 seconds without the wedge. As before, the H and K lines were invisible.

In conclusion, the Uranometria Oxoniensis shows that valuable results may be obtained with the wedge photometer in skilful hands. But the experiments described above show sources of error which must be carefully studied before we can safely apply it to stars of different colors, or to detecting small systematic errors in star catalogues.

MEMOIRS

OF

THE AMERICAN ACADEMY

OF

ARTS AND SCIENCES.

MDCCLXXX.

CENTENNIAL VOLUME.

VOL. XI.—PART VI.—NO. VII.

CAMBRIDGE:
JOHN WILSON AND SON.
University Press.
1888.

VII.

Memoir of Daniel Treadwell.

NOTE.

The American Academy of Arts and Sciences *distributes its quarto publications as often as separate monographs are printed. There has been some confusion in the designations and numbers on the covers of the several parts of Vol. XI., now completed; but the page numbers are correct, and these alone should be followed in binding.*

r, 1791, in Ipswich, one of
ɜr, Captain Jabez Treadwell,
st settlers of the town, who
nd. His mother, Elizabeth
ɔswich and Priscilla Baker,
s, — "a gentleman," says
dham in Essex, England."
in 1854 is the following

"My father and all his predecessors to the first settler were farmers, — hard-working and respectable men, none of whom have left any distinguishing mark either of their virtues or vices upon the community in which they lived. My mother, Elizabeth Dodge, was the second wife of my father, and died when I was two years old, leaving me and two older brothers (Isaac Dodge and Jabez), the oldest of eight years, without any female relation to care for us. My early years were therefore, no doubt, much neglected, as my father's housekeepers, however well disposed, possessed neither the education nor the affection required to make the most of a child, and my father, who was fifty-two years old at the time of my birth, was much occupied in the care of his farm. My father — I can remember him well, although he died when I was but eleven years old — was a staid and sensible man, — a model farmer, exact and punctual in all his affairs. The active period of his life fell upon the hard times of the Revolution, during the greater part of which his three brothers were engaged in the army. Of the bravery of one of these brothers, Captain William Treadwell of the Artillery, I remember hearing many stories when I was a boy. My father by his industry and prudence, with but little assistance from his sons, acquired a property in land which at the time of his death was valued at about seven thousand dollars. I was placed at my father's death under the guardianship of Colonel Nathaniel Wade, an old Revolutionary soldier, who was much esteemed in Ipswich for his honesty and good sense, and went to board in his family." *

* The care and kindness of Colonel Wade were always held in grateful remembrance. In Mr. Treadwell's will, made in 1819 just before sailing for Europe, after a bequest to the daughter of Nathaniel Wade, is this item: "To Nathaniel Wade, Esq. (as a token of my esteem for this respectable man, who has so long extended

VII.

Memoir of Daniel Treadwell.

By MORRILL WYMAN, M.D.

Presented October 5, 1887.

Daniel Treadwell was born on the 10th of October, 1791, in Ipswich, one of the shire towns of Essex County, Massachusetts. His father, Captain Jabez Treadwell, also born in Ipswich, was a descendant of one of the first settlers of the town, who emigrated to it as early as 1637, from Oxford in England. His mother, Elizabeth Dodge, was a descendant of Major Isaac Appleton of Ipswich and Priscilla Baker, granddaughter of Lieutenant-Governor Samuel Symonds, — "a gentleman," says Hubbard, "of an ancient and worshipful family, from Yeldham in Essex, England."

In a short Autobiography written by Mr. Treadwell in 1854 is the following account of his early life.

> "My father and all his predecessors to the first settler were farmers, — hard-working and respectable men, none of whom have left any distinguishing mark either of their virtues or vices upon the community in which they lived. My mother, Elizabeth Dodge, was the second wife of my father, and died when I was two years old, leaving me and two older brothers (Isaac Dodge and Jabez), the oldest of eight years, without any female relation to care for us. My early years were therefore, no doubt, much neglected, as my father's housekeepers, however well disposed, possessed neither the education nor the affection required to make the most of a child, and my father, who was fifty-two years old at the time of my birth, was much occupied in the care of his farm. My father — I can remember him well, although he died when I was but eleven years old — was a staid and sensible man, — a model farmer, exact and punctual in all his affairs. The active period of his life fell upon the hard times of the Revolution, during the greater part of which his three brothers were engaged in the army. Of the bravery of one of these brothers, Captain William Treadwell of the Artillery, I remember hearing many stories when I was a boy. My father by his industry and prudence, with but little assistance from his sons, acquired a property in land which at the time of his death was valued at about seven thousand dollars. I was placed at my father's death under the guardianship of Colonel Nathaniel Wade, an old Revolutionary soldier, who was much esteemed in Ipswich for his honesty and good sense, and went to board in his family." *

---

* The care and kindness of Colonel Wade were always held in grateful remembrance. In Mr. Treadwell's will, made in 1819 just before sailing for Europe, after a bequest to the daughter of Nathaniel Wade, is this item: "To Nathaniel Wade, Esq. (as a token of my esteem for this respectable man, who has so long extended

He began his grammar school studies in the free Grammar School in Ipswich; but the state of things there was found so unsatisfactory, that he with other boys was sent to the district school of the town. After his father's death, in 1803, he went to Newburyport, ten miles distant, and there continued his studies; first under the care of Dr. Samuel Dana, and then successively under that of Mr. Thomas Burnham and Amos Choate, Esq., all graduates of Harvard College. In this manner, his teaching appearing not to have been of a very high order, he received all his regular school instruction. His Sundays he spent in the family of his guardian, walking from Newburyport to Ipswich on Saturday afternoon, the usual half-holiday of the New England schools. From his schoolfellows at this time we learn that he was a pleasant, though rather sedate boy, and a favorite among his mates; that he was remarkably upright, had the confidence of his companions, was agent and treasurer in the many little pecuniary transactions common to schools, because of the exactness of his accounts and his scrupulous fidelity,—traits of character which marked his whole life. That he held a distinguished position among his fellows may be inferred from the epithet of "Captain," by which he was familiarly known to them.

The powers of imagination and composition in fruitful inventors are often early displayed. A friend in Glasgow, where James Watt was visiting when not fourteen years old, wrote to his mother: "You must take your son James home; I cannot stand the state of excitement he keeps me in; I am worn out with want of sleep. Every evening before ten o'clock, our usual hour of retiring to rest, he continues to engage me in conversation; then begins some striking tale, and, whether humorous or pathetic, the interest is so overpowering that all the family listen to him with breathless attention, while hour after hour strikes unheeded." So of young Treadwell it is related that for two or three years it was his custom to collect the boys in the warm evenings in a circle upon the grass, and delight

towards me his kind offices and this without consanguinity but from the benevolence of his nature) I give my gold sleeve-buttons which were *my father's*."

In a communication to the Boston Courier he thus writes of his guardian: "Colonel Nathaniel Wade was an officer in the army during most of the Revolutionary War. Being with the garrison at West Point under Arnold, the command of that fort by order of General Washington devolved upon him immediately after Arnold's defection. This command was held but a few days, as, upon the arrival of more troops, it was necessarily given to a general officer. Colonel Wade remained in the army until near the close of the war, when he returned to Ipswich, his native town. Upon the breaking out of the insurrection under Shays he again went into the service in command of the Essex regiment, one of the four regiments sent under General Lincoln for the winter campaign against the rebels in 1786–87. This was his last service in the field. During the remainder of his life he lived at Ipswich, honored and beloved throughout the county for his sound judgment, his perfect integrity, and his unfailing benevolence. He died in 1826, at the ripe age of seventy-seven years." His tombstone in the Ipswich graveyard bears an epitaph probably written by Mr. Treadwell.

them by extemporizing hour after hour imaginary adventures, which, wild and impossible as they may have been, just suited the taste and comprehension of his audience.

His mechanical tendencies were early shown. In his twelfth year the town of Ipswich bought a fire-engine. "This," says one of his schoolfellows, Mr. S. N. Baker, "attracted the attention of the schoolboys, and of Daniel Treadwell in particular, who resolved to make one. When finished, he announced to the boys that he would try it and exhibit it during the vacation. When the time came, the boys assembled, and we drew it to a two-story building; we went to work, forced the water on to the roof, and with a shout of joy pronounced it a success." A feat showing an amount of thought, skill in the handling of tools, and perseverance, seldom found at that time of life.

In 1805, when nearly fifteen, he went apprentice to his eldest brother, Isaac, who had just served his own time as a jeweller and silversmith, and had established himself in business in Newburyport. Here he remained nearly two unhappy and unprofitable years, although treated with great kindness by his brother. This brother had made a great mistake. He was too young, and knew too little of business matters to make his way. The times were unpropitious, and as his difficulties increased his spirit and industry relaxed, until at last, having been cheated out of a large amount, he gave up his business, and in a short time went to New York, afterwards to Caraccas, where he became Director of the Mint and the Department of Mining under the government, and perished in the great earthquake of 1812. His second brother, who had become mate of a brig at the early age of nineteen, on his first voyage in that capacity died at Havana, in 1806. By the death of this brother, and the removal of the elder from New England, the youngest boy was left without any near relative, and with none of any degree with whom he maintained a close intercourse. He was now out of occupation; neither Newburyport nor Ipswich offered any satisfactory means of learning the trade suited to his peculiar turn of mind, and in which he had now spent two years. At the age of seventeen he went to Boston. Here he became an apprentice to Captain Jesse Churchill, a gold and silversmith whose shop was near the "White Horse Tavern," on Washington and Boylston Streets. He soon became an expert workman, and that without much effort.

In early life he had few but children's books, and the Bible (then the principal reading-book of the New England schools), some translations from Virgil, Robinson Crusoe, and a few other tales; also Nathan Bailey's Dictionary, by a close study of which, he said in after life, he had gained more than from any one book he had ever owned since. In the first years of his apprenticeship at Newburyport he also fell upon an odd volume or two of Pope, Milton's Poetical Works, several of Shakespeare's plays, and the works of Sterne and Smollet, and a few other plays and novels. On his removal to Boston, finding a good library, he began to read history and the English poets from Spenser to Scott, whose "Marmion" was just published. He also studied physics and metaphysics.

In his Autobiography he says: —

> "When about nineteen I took to geometry and algebra, and went unassisted through Euclid and Bonnycastle's Algebra. Although I could not give my mind to the works of gold and silver that I wrought, I was always attentive to the operations of machinery whenever I saw them. Before I was fifteen I had gone through the necessary exercise of puzzling over the problem of 'perpetual motion.' During this labor I perceived, without aid or instruction from any one, the great principle of virtual velocities. This rediscovery, or untaught perception, of the principle of virtual velocities is sometimes given as a mark of great mental power. I am inclined to think it not an uncommon occurrence, and that most young persons of a little more than medium talent are capable of it. Of the value of a clear, constant, and vivid perception of the principle of virtual velocities to the machinist, too high an estimate cannot be formed. In this way, working with my hands upon what did not interest my thoughts, and bending my mind with its utmost force upon a world remote from my business, I reached my majority."

A friend writes of him: "He read everything good of its sort; for everything he found an appetite. Every evening and every moment when not at work he spent over his books. His head was so full of Plutarch, and poetry, and the philosophers, that he gave no time to the companionship of his acquaintance, and soon came to live in a world that most of them had no conception of. Often the young workman was found hammering on a piece of plate, with his eyes perhaps wandering from his work to a volume of Hume or some other instructive writer, which was usually open upon the bench before him." About this time, as indicating the kind of speculation in which he was indulging, and pardonable in a boy of his turn of mind, he made for himself a gold watch-key, upon one side of which were engraved "The Decalogue," "The Iliad," and "Macbeth," and upon the other, "God," "Homer," and "Shakspere."

Although he did not give himself to the mechanical work of his trade, it was not so with regard to the principles which it involved, or the methods by which it could be improved, especially its implements. In making silver-ware, the important tool in Jesse Churchill's shop was the hammer, and much of the workman's success depended upon the skill with which he could use it. With this alone, by a tedious process, the various articles were gradually fashioned, or beaten up, with little certainty of exact resemblance in articles intended to be similar. Young Treadwell made for his master a set of forms or "swages," between which the rolled plate of silver was laid, and by a few blows or strong pressure received the desired form with great exactness. About this time, having but little business and being in poor health, he made a journey southward, hoping to improve both.

> "In 1812," continues the Autobiography, "the country had just entered upon war with Great Britain. The hard times were admonishing the people not to indulge in luxuries of gold and silver, and my prospect of success was not brilliant. However, on an offer from Mr. Churchill that I should join him at once in the trade, I determined to adventure with him. I continued this partnership about four years. At the end of that time, finding that I did not advance in wealth in what I was engaged, and my attention being turned more and more to the operation of manufacture by machinery, I engaged in the invention of a machine for making wood screws; that is, the screws used by carpenters and cabinet-makers for fastening together their structures. I undertook this machine in connection with Mr. Phineas Dow, a man of considerable skill and ingenuity, who was ten years my senior. We were engaged at first irregularly upon this machine about two years, when it was finished in an imperfect form, and with the aid of a friend, General William H. Sumner of Boston, put in operation in a mill at Saugus. It performed the operation of making the screw entirely without the aid of the hand: taking in the wire at one end, it delivered a finished screw at the other. It was therefore very complicate, but much admired for its ingenuity. It was never made really practically successful in the form in which we made it, but it contained many of the elements upon which the screw machinery of the present time is constructed."

Mr. Dow says: "Mr. Treadwell was at work through the day as apprentice, journeyman, or partner with Mr. Churchill, a silversmith, whose shop was next mine, but the evenings of more than a year were spent in my shop, where we together invented, built, and perfected the machine." They found it difficult to get suitable wire; none was made in this country, and the English wire during the war of 1812 was costly and hard to obtain; and capital was not abundant with them. After a while came the peace with Great Britain, and imported screws again appeared in plenty. In September, 1817, the machine was sent to Philadelphia, and, after being exhibited awhile, was sold with the right of using it for about $5,000. The inventors had counted largely on the continuance of war and the "Non-Importation Act" to give them a monopoly of screw-making, and a chance to get rich; this the return of peace spoiled.

The petition of Phineas Dow and Daniel Treadwell that letters patent may be issued, is addressed to John Quincy Adams, Secretary of State, and is accompanied by a "specification of a machine for making screws of metallic wire, commonly called wood screws, at one operation, by water, steam, or any other power." The machine as described is divided into three sections: "First, the feeding in the wire, cutting it off, heading it, and discharging the screw blank thus made from the heading section. Second, the feeding the blank into the holding gripes, and cutting the screw. Third, the slitting or sawing the groove or screw, polishing the head and rounding the same." A patent was obtained, but an intelligible description cannot be given without drawings which are not preserved. The specification closes as follows: "We may remark, that, with a good water or other power, a machine such as has now been described will make from eight to twelve screws per minute." *

Notwithstanding his devotion to manufactures, he was still a student, and during the winter of 1817 devoted a portion of his time to the study of French, under the direction of Mr. Joseph Bourgon, at that time a teacher in Boston. This was all the regular instruction he received after leaving the school of his native town.

His next invention was a machine for making wrought-iron nails. It made finished nails, with heads and points complete, from heated nail-rods fed in from above. Of the arrangement of the various parts little is known — no complete description having been preserved — except that it contained four hammers, probably moved by cams, which gave the requisite blows to form the rod. About the time it was finished and at work, an Englishman appeared and claimed priority of invention, although his machine never made a perfect nail. Mr. Treadwell declined to contend with him, and abandoned the business. It would seem, however, that his invention, either as thus made, or with some subsequent improvements, was again put in operation, for he was employed on the mill-dam of the Boston Water Power Company in the manufacture of nails from 1824 to 1827; although, as he afterwards remarks, not with great profit.

Mr. Treadwell's health, never vigorous, was much impaired by the great energy with which for several years he had devoted himself to his mechanical pursuits; he had been obliged at times to give up all work, and go to his native town for rest and recreation; one summer was spent in a voyage among the islands along the coast of Maine. But with all his care he found himself unable to return to his trade, and in February, 1817, the firm of Churchill and Treadwell was dissolved by mutual consent.

"Worn out with the anxieties of this work, I determined to attempt a change of pursuits, and at the age of twenty-seven commenced the study of medicine. I had previously formed a

---

* March 11, 1818, a model of this machine was sent to the Patent-Office at Washington. This with the drawing was probably destroyed in the burning of the office, in 1823.

> slight acquaintance with Dr. John Ware, of Boston, then just commencing the practice in Hanover Street, and, although he was my junior by four years, I began as a student under his direction. This was the commencement of a friendship, which has continued without interruption for thirty-six years, and from which I have derived many very great benefits. Dr. Ware had received the discipline of a regular college education, while my mind had been pursuing knowledge with great ardor, but wholly undirected. He at once received me upon something like terms of equality, considering my age as nearly an equivalent for his rank as master; and in the free discussions which have been maintained between us during our long intimacy I have received a constant advantage from the check of his organized learning, and, with the exception of two or three subjects, admirably proportioned mind; while I hope he has now and then received some benefit from the more free and unfettered, not to say original views, that the mind without early discipline is likely to take of the great subjects of thought.

While studying with Dr. Ware, Mr. Treadwell made the acquaintance of several young men, who were either students, or who had just commenced the practice of medicine; among them Dr. Jacob Bigelow, and Dr. William Sweetser, afterwards Professor of the Theory and Practice of Medicine in Bowdoin College and at Castleton, Vermont. "His fellow students," says Dr. Sweetser, "held him in much esteem and respect for his great scientific knowledge, and his intellectual superiority, which we, his friends, did not hesitate to acknowledge. I became greatly attached to him at that time, and that attachment has never met with any interruption."

To an acute observer like Mr. Treadwell, trained in the practice of the mechanic and hydraulic arts, anatomy and physiology — the animal at rest and in motion — must have been peculiarly attractive. He must have found in the animal economy many illustrations of his favorite pursuits, — illustrations little noticed or entirely overlooked by those who had acquired only the ordinary preparation for a medical student. At this time, as appears from a rough draft among his papers, he undertook the solution of that difficult problem, the work done by the heart. Taking for his data the height of a jet of blood from a severed carotid artery, and the diameter of the aorta, he compared them with what is known by mechanics as a "horse-power." His conclusion, it is safe to say, was nearer that now accepted by most physiologists than that of many who had preceded him in similar inquiries. Besides such investigations, he carefully considered the method by which the forces of the human body can best be applied to the movement of machines, and soon put his views in practice. Nor was his interest confined to the mechanical relations alone; as we shall see further on, he made investigations and experiments not without interest to the physiologist.

"After studying with Dr. Ware about a year and a half, my health improved, and with it my mind returned to its old habits of ranging upon mechanical operations. Examining the various ways of applying the force of the muscles of the limbs to the motion of machines, and being aware of the fact that in the human subject the lower extremities are vastly more powerful than the arms, it occurred to me that this circumstance might be taken advantage of in the construction of machines which are operated by human force, particularly when a considerable expense of that force is required without any great accuracy in its immediate direction. After some deliberation I selected the printing-press, as connected with one of our most useful arts, and as well fitted to illustrate the principle assumed. On analyzing the various actions of the common press, I became acquainted with other facts which confirmed me in my choice. I found that in the common press two thirds of the power applied to it was exhausted in conquering the elasticity of the materials of which it is made, and that in the iron presses which have been recently introduced this elasticity, though lessened, is still the cause of a notable loss of power; for iron, and all materials of which a press can be made, are more or less elastic; besides this, the actual interposition of some very elastic body between the platen and the types is absolutely necessary. Now, as the reaction of an elastic body is equal to the force actually expended in its compression, it was obvious that, if a press were made to operate by the gravity of the body, a power which acts without any fatiguing muscular exertion, and gave the impression by a mere descent of the operator, such a press would relieve him of an amount of exertion equal to the whole reaction of the elastic parts of the press, and if the force which would then be required of him were obtained from the muscles of the legs instead of those of the arms, I was confident that it would be improving the press in an essential degree. It was these views of the case which led me to contrive a frame, levers, and joint similar in principle and mode of action to those used in my present press. I preferred the lever to any other mechanical power; and for the 'toggle joint,' through which the weight of the operator is communicated to the lever, it has the essential advantage of becoming more powerful as it advances in its course, and that in a ratio nearly corresponding, in the printing-press, with the increase of resistance. At this stage of the invention I became aware of the advantages which would result from rendering the 'form' stationary. To accomplish this, one obvious mode would be to unite the platen with the 'tympan,' but some mode of counterbalancing the weight of the platen, other than by an equal weight acting simply on the other side of the axis on which the platen rotated, must first be contrived; for if that mode were adopted, the platen and its counterbalance would take up the slow oscillatory motions of the compound pendulum, besides having a great amount of *vis inertiæ*, which must be overcome by the operator four times for each impression. In the counterbalance which I have adopted, the force acts always in opposition to the weight of the platen, and its velocity is so great that it can receive no impulse from the action of the platen which shall essentially lessen its force. Still, however, it is desirable to make the platen as light as may be, without in any way yielding or springing in taking the impression. My contrivance for diffusing the pressure on various points of the platen, by means of numerous bars arranged to form the skeleton of a pyramid, had this object in view, and enables me to make a platen in every point as strong as the common platen with a much smaller quantity of metal or wood. As to my contrivance for turning the sheet, experience proves it of some importance in the economy of the time of the operator. There are various other moving parts in my press which are new, or are not to be found in the common press. The motions obtained from these are necessary, and whether they might be better obtained from some other arrangement or organization I leave to others to determine. I can only say that the motions are produced by machinery the most simple in my power to contrive."

The principles and reasoning so clearly expressed in this example of good writing upon a combined mechanical and physiological subject were carried out in a press constructed in 1818, differing from the ordinary hand-press in many respects. In the latter, the "form" of type is upon a movable "table" or carriage, on which it can be run in and out beneath the platen, a plain piece of solid wood or metal covering the face of the form, and which, when pressed down by a powerful screw and lever pulled by the arm of the workman, gives the impression to the paper. In Mr. Treadwell's press the form is stationary, and the platen, which is light, with its tympan and "frisket," turns upon a horizontal hinge, and is so counterbalanced that it can be turned on and off the form with very little force. The impression is given by a lever, which rests upon projecting pieces of metal rising from the top of the platen. This lever is connected by a descending rod with a treadle near the floor; upon this the pressman treads with his whole weight, and, thus straightening the "toggle joint,"* brings down with great force the platen upon the types. The time and power lost in moving the form are saved, and the muscular effort is a step instead of a pull. To this is added, by means of a double frisket, a mode of reversing the sheet applicable to half-sheet work, so that it may be printed on both sides without shifting. This was called the "Treadle" or "Foot Lever Press." The construction and manner of working will be understood from the following description and illustrations, taken from Hansard's Typographia, p. 659.

"Figure 1 represents a side view, with the tympan and the frisket folded upon the platen, and the platen turned down upon the form. Figure 2 represents a front view, with the platen turned up off the form, and the frisket open. The action of the press is as follows.

"Having placed the sheet of paper to be printed upon the tympan, *a*, fold down the frisket, *b*, upon it as usual, and then turn over the platen, *c*, down upon the form, *d*, as seen in fig. 1. To obtain the pressure, the workman then steps upon the treadle, *e*, which brings down the bar, *f*, and by means of the knee-joint, *g*,* the arms *h* and *i* become straightened, and con-

---

* Mr Treadwell gives the following account of the origin of the toggle-joint, or "knee-joint," now so commonly used in machinery: —

"The toggle-joint, although to be found in principle in the crank and connecting rod, and in many other combinations, was first brought into use, in its present distinct form, by Mr. Jacob Perkins, of Newburyport, Mass., about the year 1800, or a little before that time, in the nail machine then invented by him. It was hardly known to the English machinists in 1820, who, on adopting it, gave it the name of the 'end lever.' The name toggle-joint was said to have been given by Mr. Paul Moody, who commenced his career as a workman of Mr. Perkins, and ended it as chief engineer of the works at Lowell, of which city he was one of the principal founders. Mr. Wells might have been the first to use the toggle-joint in its simple form in the printing-press; but Medhurst had made a very near approach to it in his press, invented not long after the date above assigned to the distinct introduction of it in the nail machine."

sequently, the main lever swinging upon the pivot, *j*, is raised at the hinder part, *k*, and depressed at the front part, *l*.

"Thus the descent of the lever at *l*, by the means above described, throws a great weight upon the platen, for the purpose of imprinting the sheet of paper previously (as above) placed between it and the form of types, *d*, which is upon the table.

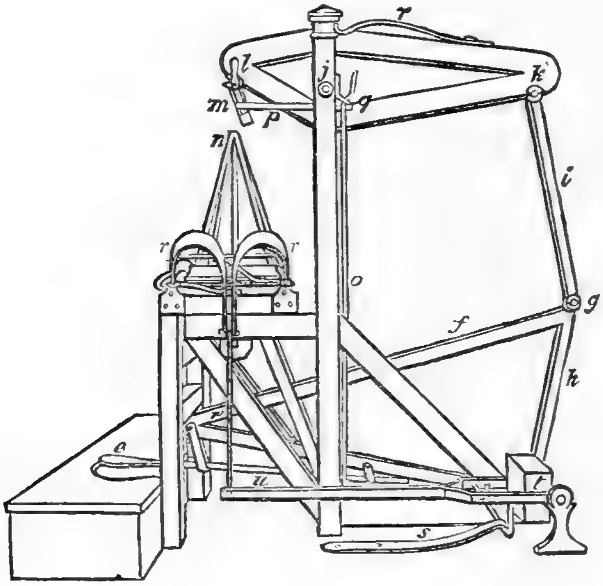


FIG. 1.

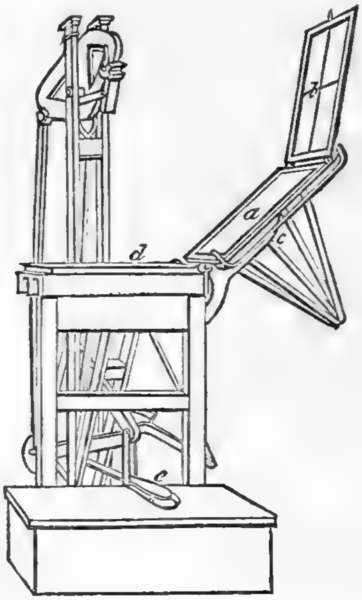


FIG. 2.

"By the descent of the treadle the instant before the impression is given, another action is also obtained, for the purpose of bringing the hammer, *m*, into a perpendicular direction, in order to meet the block, *n*, where the legs of the platen all unite. The rod, *o*, attached at the bottom to the treadle, *e*, communicates also near its top by a connecting bar, *p*, with the hammer, *m*. The top of the rod, *o*, is bent, and as it slides down through a guide, *q*, by the descent of the treadle, the connecting bar, *p*, moves the hammer, *m*, from its inclined pendent position into a perpendicular, ready to press directly upon the block, *n*, of the platen.

"When the foot of the workman is removed from the treadle, *e*, it rises by the reaction of the compressed parts aided by a spring, *s*; at the same time the hammer, *m*, shifts from the block, *n*, in order to allow the platen to rise, and the type to be inked afresh.

"The platen and its arms being of considerable weight, a counterpoise, as it turns over, is effected by the spring, *s*, and weight, *t*, acting upon the frame or lever, *u*, which by the rod, *w*, hanging upon the bent arms, *r r*, of the platen, balance its weight, and render its motion easy to the workman.

"Figure 3 represents the platen, tympan, and frisket detached from the press, for the purpose of exhibiting their parts and actions more distinctly, as respects the method of reversing the sheet without removing it from between the double frisket; *c* is the platen, upon the sides of which are two pivots; *x* is a bar connected to two arms, *y y*, in which the double frisket is

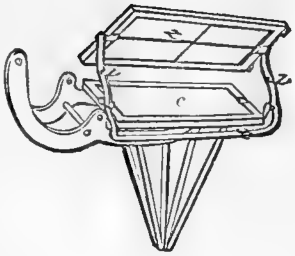


Fig. 3.

> enabled to turn over upon centres; when the sheet is printed on one side and the platen thrown open, the bar, x, is depressed by the right hand, which raises the double frisket holding the sheet of paper, z; the left hand then instantly turns it over, and the sheet is, by another impression, perfected.
>
> "There is certainly great originality in the construction of this press: its operations are conducted with much facility by one man; and as the rolling of the table and the horizontal movement of the bar are dispensed with, the labor must be considerably reduced. The chief objection which struck me, on a view of it, was the room required behind the press, four or five feet more in width than any other press. This, in the confined space and value of house-room in London, would, in itself, be a sufficient objection."

This press excited a good deal of interest among printers. Colonel Benjamin Russell, an old Boston printer, and the well-known editor of the "Columbian Centinel," was much pleased with it, and brought it prominently forward. The same friend, General William H. Sumner, who had aided Mr. Treadwell in the screw machine, aided him in this also. The press, when finished, was put in operation in Boston for a short time, and worked so satisfactorily that it was determined to bring it into general use. Mr. Treadwell wished to visit England, and decided to make his first attempt there. He sailed for Liverpool on November 6, 1819, and reached London in December. Thence, after making arrangements with Mr. Napier, a prominent manufacturer of printing machines, for the construction of his press, he went to France, remaining there through February and a part of March, when he returned to London.

His experience in England is related in the following letters from London to his friend and medical instructor, Dr. John Ware, afterwards Hersey Professor of the Theory and Practice of Medicine in Harvard College, and one of the most eminent of Boston physicians.

To Dr. John Ware.

London, January 20, 1820.

I promised you in my letter dated at Liverpool that you should hear from me again soon after my arrival in the great city. I fulfil my promise the more readily that I may put you in possession of my address that I may receive from you the good office of a letter. I arrived in London on the 7th of December, having left Liverpool on the 3d. My journey was through the heart of the land, which does not appear generally better populated than the sea-board of New England, (I except Birmingham and the great inland towns, of course,) and I did not notice anything of that appearance of superior comfort of which Englishmen always boast as so striking to the foreigner; but my standard of comparison was New England, where comfort is the common boast. That which excited my admiration most was the numerous old edifices I met at every few miles of my journey, — not, indeed, castles of armed barons, but churches and abbeys, which boast an antiquity beyond the Norman Conquest. At Litchfield I stopped a day, and went over the Cathedral, which was built about the year 670. It is an immense Gothic pile, and *even I* felt something like religious awe in wandering amongst its dark and half-decayed statues and monuments. At Stratford I employed the five minutes allowed for changing horses in getting a sight at the house where Shakespeare was born. (I had walked two or three miles in Litchfield to see the house famous for the birth of Dr. Johnson, and a great willow tree said to have been planted by his own critical hand.) In this, however silly I might be, I followed my feelings, and, remembering how strong they were, no longer wonder at the religionist for worshipping the relics of his saint. . . . For a subject which I know will interest you — my prospects of success in my pursuits — I can only say, that I have not been crossed by any invention here resembling mine, that, after attending to many troublesome and expensive formalities, I have obtained the signature of George the Prince to my patent, and that it will in all probability pass the Great Seal in a few days. . . .

Mr. Jacob Perkins, who you know came some months ago to London for the purpose of introducing into the Bank of England his improvements in making bank-notes, is, in his profession, far behind Jackson or Gorham in theirs. His knowledge in practical mechanics is not so clear, perhaps, nor so voluminous as theirs respectively in medicine and chemistry, but he is pushed forward by both philosophers and simple mechanics. Some one said of Lord Chesterfield that "he was a wit among lords and a lord among wits"; this, by substituting other terms, might be made applicable to Perkins. He enjoys a high reputation amongst mechanics and artists, and from the present state of my knowledge of the English inventive mechanic he deserves to rank with the *highest of them.* I have received much attention from him since my arrival in London; he is a man of considerable merit, and has shown *his wit by admiring my press.*

Truly yours,

D. Treadwell,
Virginia Coffee-House, Newman's Court,
Cornhill, London.

To Dr. John Ware.

London, May 3, 1820.

Dear Sir, — Your very welcome letter reached me yesterday. You promise me another soon. There is no vessel up now for Boston, but I thought I might as well commence writing now, and by having a letter prepared I shall not miss the first conveyance. . . . Now this is on the supposition that I remain here, — which is, by the by, very doubtful, for I have but small encouragement. My press will at most make its way but slowly, as it will have to conquer the prejudices of stubborn men, whose old habits of working are not to be altered in a day, if ever. Should I not meet with such success as to encourage me to stay, (and this I shall now be able to determine soon after I have a press in operation,) you will hear of it before you have a chance of answering this. Indeed, you must not be surprised should you see me in Boston in a few months; for as I would not think of spending my life in Europe under any circumstances, so I shall leave it soon unless I can remain to some purpose. I passed part of February and most of March in France; I could pass a year in that country very well, but after all America, with her simple institutions, is the country for me. In this old and rotten world kings and lords strut about in bombastic pomp, as though it was made for them alone, and all the people were nothing. Your kind attention to my *Faith* deserves my gratitude. I consider the Christian's belief as of more value than anything else he can possess in this world; but from the peculiar construction of my mind I sadly fear that it is a treasure not for me. I shall certainly read Butler's Analogy, as you recommend. If I recollect rightly one of the Apostles, or some churchman, has said, 'Lord, help my unbelief.' Now, if I could gain this by asking, I should ask loud and often. Still I hope that you do not put me down for an outright Deist, but merely a sceptic in religion. I would believe because I admire the character of Jesus Christ, and, more than all, because I think the immortality of the soul cannot be proved by natural religion, and there is something inexpressibly cold and gloomy in the bare idea of annihilation. I could almost as comfortably think of going to Purgatory as being annihilated. I am very sorry to find that you estimate my intellectual properties so highly; for I am sure, very sure, that you have valued me much beyond my deserving. Consequently, the correction of your judgment must end to my shame, — for of all things it is the most mortifying to fall in the estimation of those by whom we wish to be thought well of. You say there are only a few persons in this wide world that you feel perfectly at home with. I supposed that I was the only human being so solitary, and I am rather pleased to find myself supported by your authority in being alone though surrounded by all the world.

I shall derive some advantages from this voyage, although it should not be successful in its particular object; for there is much for an American to pick up in England by looking at the bad side of the picture, and for the most part it is but a poor daubing. I am happy to learn that our friend Dr. —— is so-so. I ought to have written to him, and should long ago, but that I knew he would see my letters to you. I do not forget him nor Dr. S——, and I hope in return to be remembered by them whenever the blue devils (and I suppose they have not yet been all laid in the Red Sea) are not tormenting them. When I left Boston I intended to have paid considerable attention to the lectures here, but there have been so many calls on my time, and my mind has been so engrossed by my particular affairs, that I have not been able to attend to them. Quacking is carried on in the most neat manner imaginable in London. To give you an instance. A fellow by the name of Daniels, who kept a shop a few years ago in the Strand for selling life-preservers, as he called them, — that is, cork jackets to swim with, — all at once turned his shop out of doors, and, assuming the name of Dr. Cooper, procured a carriage painted to imitate Mr. Astley Cooper's, and commenced advertising to do everything but raise the dead; there are hundreds who go to him believing him to be in fact Mr. A. Cooper. It is said he has made quite a fortune. There are many other instances of as outrageous fraud as this. One cannot walk half a mile in one of the principal streets without having half a dozen quack bills put into his hands. I shall write to you again very soon. The English are wonderfully ignorant of all that relates to America (which they affect to despise); this is decidedly to our advantage, for we learn from them, and have our own improvements in knowledge to boot.

With sentiments of the highest esteem, believe me to remain, dear sir, yours,

D. TREADWELL.

TO DR. JOHN WARE.

LONDON, July 8, 1820.

. . . As I do not meet with that success which I thought I had a right to expect, I shall in all probability see you soon after this reaches you. There are several causes which prevent my succeeding, all connected with the extreme caution and narrow views of the printers. The system on which a person is brought up to a *trade* in London makes him mechanically perfect in it as it is there practised, but altogether prevents him from acquiring the philosophy of it, as is very often the case with people in our own country. . . . I shall leave my concern in a way that it will probably get along slowly, and on my return to America I hope to *get up* an establishment that will not depend on a trade for its success.

I am quite disappointed in the English mechanicians. I find none among them men of enlarged, well-arranged minds, and I have had opportunities of seeing some of the most eminent.

You have no doubt heard of the Society of Arts. It is, to be sure, a body too numerous to rank very high, but it is headed by the most popular of the royal Dukes, and is always spoken of as respectable, at least. I have attended two or three of their meetings, and was astonished at the trash and nonsense I heard. The English are before us in many things, but they owe this to other causes than their superior genius, as they insolently imagine. A nation seen at a great distance either of time or place appears vastly above its true dimensions. John Bull is thought a great deal too much of in America. He is haughty and overbearing, and no friend of ours in any sense of the word, and it is both useless and degrading to coax him; he would respect us more if we were less humble to him. You are perfectly right in your prediction of some revolution in the system of government in England, and it might be extended to Europe generally. Thrones are preserved by the bayonet now, but it cannot last always. It is astonishing to see the confidence which the English have in their complicate and rickety old government. They say that its fall has been predicted every year for the last half-century, and as it has not taken place yet, they do not believe that it ever will; as well might a man of seventy hope to live *ad infinitum* because he had lived so long already. Certainly experience is of all things the most worthy of trust, but the experiment in this case has not been finished.

Any man who has one drop of the milk of human kindness in his veins must feel sick at heart to see the misery of the poor, contrasted with the useless luxury and extravagance of the rich. The slaves in Virginia are much better fed and clothed than one quarter of the population of this country, and, bating the odium of the term slave, they are to all intents and purposes as well conditioned.

The following shows the certainty of conclusions drawn from chemical experiments. At a late trial before Lord C. J. Dallas (a fire insurance cause), £70,000 depended on this question: "Is it more dangerous to boil sugar (in a sugar-house) by passing heated oil through it in tubes or pipes, than to boil it in the old way?" namely, by putting the fire directly under the sugar pan or pot. The great guns of chemistry were called in evidence. Parkes, Brande, Accum, and several others, swore that they had made many experiments to ascertain the truth, and they had no doubt but the method by oil was much the least dangerous. Childern, Bostock, Faraday, and several others, swore they had made experiments also, and they had no doubt but the oil method was much the most dangerous. Lord Dallas in the charge said: "This is not a day for the triumph of science. The first chemists in the world are brought forward, and they give us no light. When we see them drawn up in hostile array against each other, what are common men like us to do? For me, my mind is surrounded with doubts which are not likely to be removed by opinions so contradictory."

Ever your friend,

D. TREADWELL.

The press was completed in May. A description of it, and of the advantages expected from its use, was printed and distributed among the London printers, together with a circular under date of May 20, 1820, as follows: "A printing-press on a new and simple construction, in which the form is stationary and the impression is given by a treadle, is now in operation for the inspection of the trade at No. 80 Long Acre. As the press is not only cheaper, but works with less labor and more expedition, than the presses in general use, the inventor has a confident expectation that it will meet the approbation of the trade. He takes the liberty of inviting you to witness its operation." Two or three presses were built and put in operation, but, notwithstanding some unquestioned advantages, as above stated, the press did not find the favor that was expected. Mr. Hansard, whose description we have given, bears testimony to its originality, and also to the fact that it requires but one man. Further, that some of the movements required on the common hand-press are dispensed with, and by means of the springs and counterbalance others are rendered easier and more rapid. The probability is, that the objection among the workmen was principally in that unwillingness, if not inability, of most mechanics to change the work to which they had been accustomed from their apprenticeship for that which requires some new practice in order to become expert. Presses worked with a treadle and a fixed table are now in general use for the printing of small forms, cards, and other light work.

Mr. Treadwell, finding that his prospect of success did not warrant a further stay, returned to Boston in September, 1820.

The attention of printers at that time was directed almost exclusively towards steam printing. On Monday, the 28th of November, 1814, the London Times had already announced to the reader that he held in his hand a paper printed by steam. Mr. Treadwell writes in the Autobiography: —

> "After an examination of the steam cylinder press while in England, I concluded that a better steam or 'power press' for book-work might be constructed by using the platen instead of the cylinder for the impression. All the English machines gave the impression by cylinders, which, while they are capable of executing work more rapidly, do not give so fair and clear a page as can be produced by the flat surface of the platen. Soon after my return I began the construction of a machine to print by 'Power.' It was completed in about a year, being the first press by which a sheet of paper was printed on this continent by other than human power. All the operations except supplying and removing the sheets were automatic, derived from a rotatory shaft worked by a horse. The press worked regularly as to time, making its nine or ten impressions between fifty-eight and sixty-two seconds. Although constructed in 1821, it was not patented till 1826, which added by so much to the fourteen years' monopoly."

The construction of this press may be understood from the accompanying figures, which were drawn, with the exception of Fig. 4,* from two presses made at different times, with a different arrangement of some of the parts. The original drawings, filed in the Patent Office with the specification of the patent, were there burnt in 1835 or 1836. In both figures, *a* represents the frame, *c*, Fig. 4, the main shaft, coupled below the floor to the moving power. *o o*, Figs. 4 and 5, is the platen; *y*, the bed with the form of type; *k* is the toggle-joint, fixed to the beam, *a*, above, and the platen, *o*, below, by which the platen is moved in making the impression; *m*, a plank on which the bed runs when drawn from under the platen. *d*, Fig. 4, is a cam on the shaft, *c*, seen at *f*, Fig. 5, which, when revolving, acts through the slide bar, *h* (the bar is fitted with a friction roller), on the toggle-joint, *k*, which it straightens, and thus presses the platen upon the types. The platen is counterbalanced and drawn upward, and kept pressed against the toggle-joint by a lever and weight above the top beam connected with the platen by a rod represented by the dotted line. The bed or carriage, *y*, on which are the stone and types, is moved back and forth under the platen on railways resting on the plank, *m*, by the following described machinery. *p*, Figs. 4 and 5, is a shaft or verge with a gudgeon at each end running in suitable boxes; upon this are two mitre cog-wheels, *q q*, of eight inches in diameter and eight inches apart; these gear, one into the upper limb, and one into the lower limb of the vertical wheel, *r*, of the same diameter. The two cog-wheels turn freely on the verge, but are kept from moving up and down by collars. The vertical wheel drives the upper cog-wheel in one direction, and the lower one in the opposite direction. The shaft of the vertical wheel, Fig. 4, has upon its other end a vertical wheel, *i*, which is driven by a crown wheel, *g*. The portion of the verge between the two cog-wheels *q* and *r*, Fig. 4, has upon it a chuck or clutch, which is two inches less than the space between the two wheels; this clutch can move freely up and down on the verge, but is so

---

* Figure 4 is made from the specification, without reference to any drawing. The pressman is supposed to stand on the south side of the press looking to the north, having the east end of the press to his right hand, and the west end to the left. The terms east, west, north, and south are used to designate the aspect of the parts, or directions in which they are placed in regard to the centre of the whole, which is a vertical line drawn through the centre of the platen. As the distances of the various parts from the frame of the press are given, and also their dimensions, it has been possible to reproduce the drawing in its essential parts.

In a letter to Mr. William Van Norden, of New York, who at one time intended to publish a History of Printing in America, Mr. Treadwell says: "You will see that the specification is drawn up in a very unusual manner, bearing no reference to any drawing, although a good drawing was made and filed with it in the Patent-Office, where it was burnt in 1835 or 1836. The specification was made in this way, I may say in *caprice*, to show that I could make a description that would answer the requirements of the law by the use of words alone, without any aid from a picture representation." In another letter to the same: "In whatever you write, remember that when I made this press I was a *mechanic*. The press was not the invention of a *professor*."

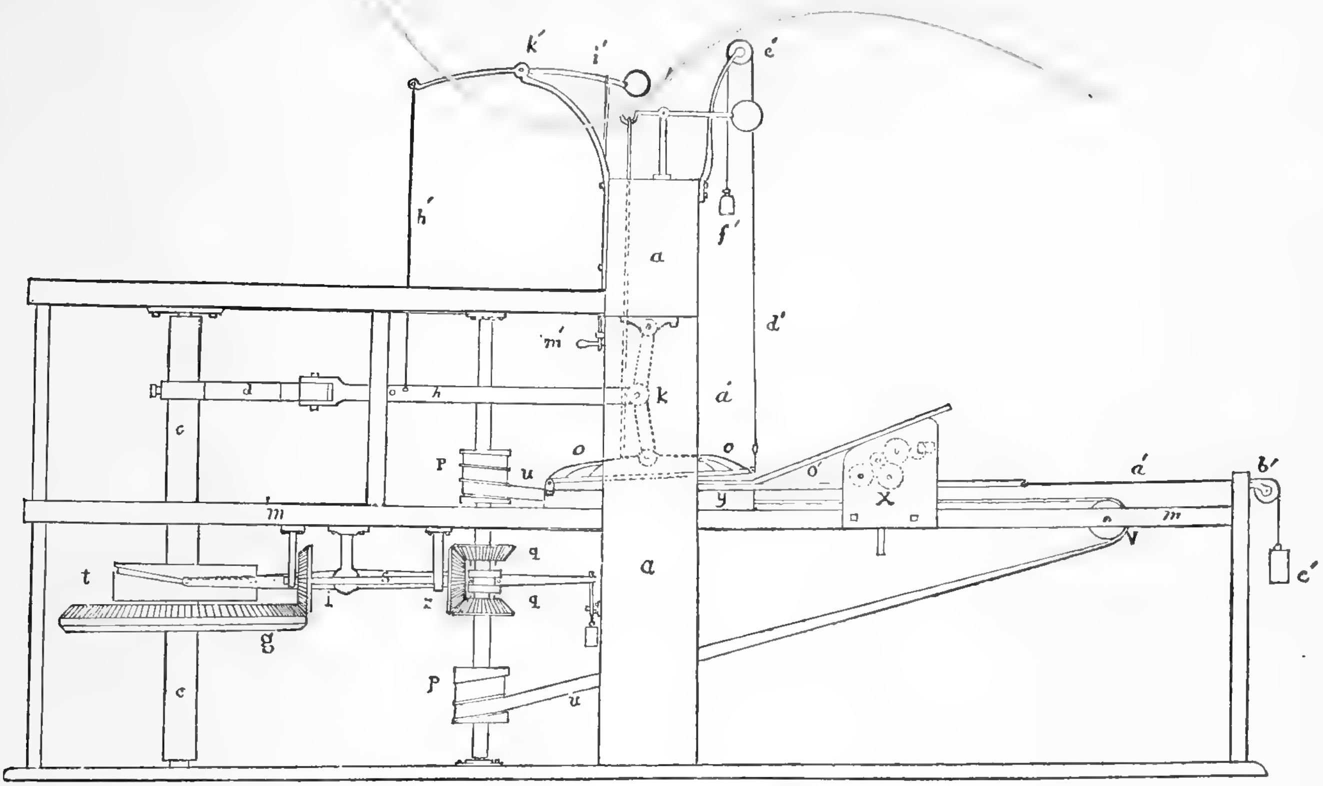


FIG. 4. POWER PRINTING-PRESS.

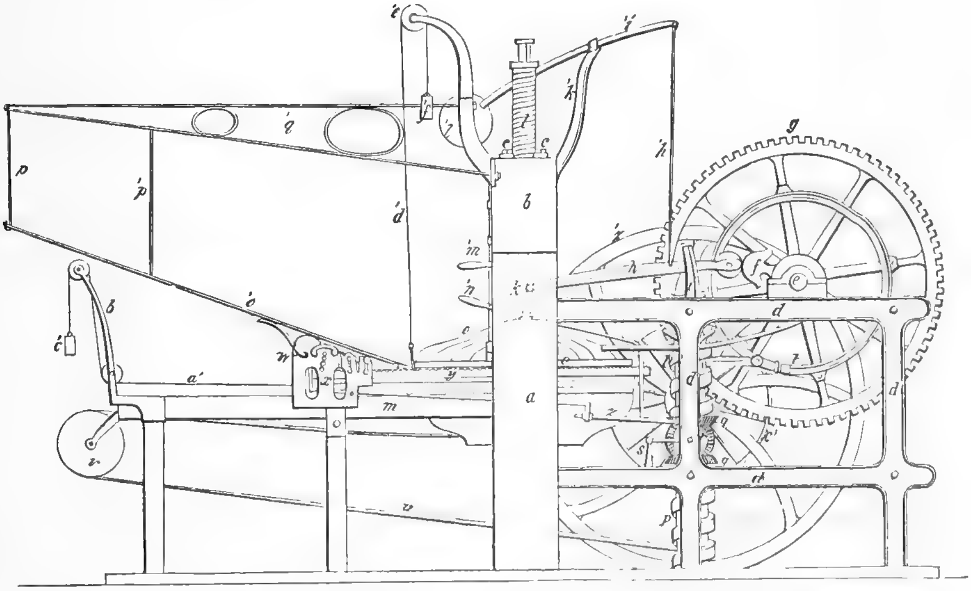


FIG. 5. POWER PRESS WITH FLY-WHEEL.—IMPRESSION GIVEN BY A VERTICAL WHEEL.

fixed to it by wings that the verge and clutch must revolve together. Each of the cog-wheels has two pins diametrically opposite each other, the upper pins pointing downward, and the lower pins upward; the clutch has corresponding slots to receive these pins. The clutch also has around it a groove which receives the forked end of a lever, *s*, turning on a pin, *i*, as a fulcrum. The opposite end of the lever fits into a groove in a horizontal wheel, *t*, Fig. 4, 18 inches in diameter and 4½ inches thick, fixed on the main shaft, *c*. (Fig. 5 shows a different arrangement of the groove on the wheel *g*.) The groove on the periphery of the wheel is cut in a waving direction, so that during one part of the revolution the end of the lever in its groove shall be depressed, at another raised, and at still another stationary; the other end of the lever moving the chuck in the opposite directions. Upon the upper and lower portions of the verge are fastened two cylinders of wood, *p*, *p*, Figs. 5 and 7, to wind up two straps; one, *u*, fastened by one of its ends to the lower cylinder, and by the other, after passing around the pulley, *v*, to one end of the carriage; the other strap, *u′*, fastened to the upper cylinder, runs more directly to the opposite end of the carriage to which it is fixed. By this contrivance, when the end of the lever, by means of the grooved wheel, is moved up, remains stationary, or is moved downward, the clutch locks with the corresponding cog-wheel, and winds up the strap, drawing the form of types under the platen, where it remains stationary long enough to get the impression, and is then drawn by the other strap from beneath the platen, to repeat the operation.

The paper is carried to its place for printing by the following apparatus. On each side of the bed, *y*, is a narrow bar of iron or slide about five feet long; pieces of iron with oblong holes are fixed to each side of the bed through which the slides can move back and forth 2½ feet in each direction. To the ends of the slides are fixed upright pieces of iron, rising an inch or more above the bed; in each piece of iron is a half-inch hole. A frame or frisket of iron is made of the usual size; on each side of this, at one end, are two projecting gudgeons, which fit into the holes in the sides so that the frisket can move back and forth with the slides, and also up and down on its gudgeons as a hinge. At each of the two corners of the frisket farthest from the gudgeon are run out from the sides two pieces of iron, each three inches long, called lifting-studs. Attached to the frame of the press, a little above the level of the bed, and rising upward at an angle of 18°, is a sheet of iron, *o′*, which has firm raised edges of iron, one on either side. To one end of each of the frisket slides is fastened a cord, *a′*, which runs over pulleys on the arm *b′*, and has at its other end a weight, *c′*, which pulls the frisket slides up against the bed, and forces the frisket to move with the bed through a part of its movements. To that end of the frisket which has the gudgeon a cloth twenty-six inches square is fastened; the other end of the cloth, which is loose, is raised vertically and stretched by a stick; at each of its corners is a cord, d', which goes over a pulley, e', and has at the other end a weight, f'. The frisket slides are prevented by proper stops on the rails from running farther out from the platen than just to bring the gudgeons to its edge. If, now, the press is put in motion, the bed, which is moved by the strap u, and the frisket, which is drawn by the weight c', move out from the platen; the cloth is drawn up by the weight, f'; the lifting-studs of the frisket bearing the printed sheet strike the raised edge of the apron, o'; the frisket rises upon it until the ends of the slides strike the stops, when it remains on the apron motionless, while the bed moves on. While the frisket is at rest, the printed sheet is removed by hand, and a fresh sheet laid on; the bed then returns beneath the platen, and the operation is repeated.

The inking apparatus is placed in the frame x, Fig. 6. It consists of four rollers, three of them of the soft composition of glue and treacle, in common use, 3 inches in diameter, and one of them of wood, $2\frac{1}{4}$ inches in diameter. Two of the soft rollers lie side by side without touching each other, and at such a height in the frame, x, as just to press lightly on the face of the type when it passes under them; the third soft roller is above the others, and does not touch them. The wooden roller is in contact with all the soft rollers, and is driven by a wheel fixed to its axis, which is in turn moved by a rack five feet long attached to the side of the bed. The ink is in an iron box or fountain, y', two feet two inches long, three inches wide, and two inches deep. One side of this box is removed, and its place supplied by an iron roller, which, being turned slightly by each movement of the bed, distributes the ink on the soft roller. An important part of the distributing apparatus is a horizontal revolving table, z, 28 inches in diameter, which, turning partly round at each movement of the bed, brings constantly new parts in contact with the inking roller, and thus equalizes the distribution.

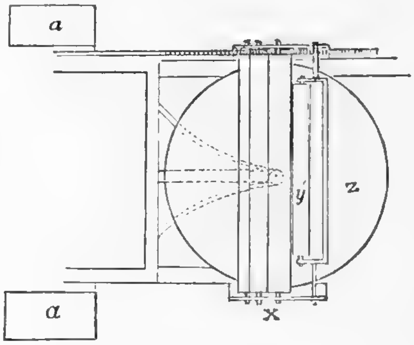


Fig. 6.

The press is thrown out of gear, so far as the movements of the platen are concerned, by means of the rod h', which is fixed to the bar h, and the lever i, resting on the arm k', and counterbalanced by the weight l'. By pulling down the handle, m', the rod h' is drawn upwards, and the slide bar h raised and detached from the cam, *d* or *f′*. The movements of the bed are arrested by means of a lever, which removes the groove lever from the groove in the wheel *t*.

They were usually arranged in pairs, as in Fig. 7, driven by one wheel between them, and giving the impression on each alternately.

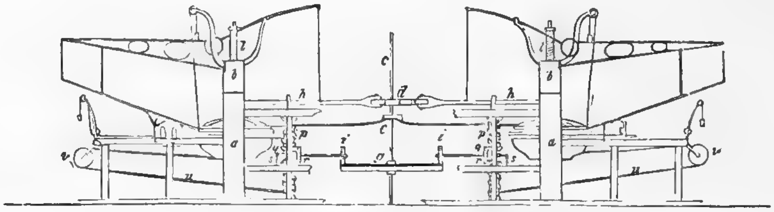


FIG. 7. DOUBLE-ACTING POWER PRESS.

The specification accompanying the patent fills twenty-six pages. It is dated March 2, 1826.

This press was constructed under considerable difficulties. The mechanic arts in Boston were far from flourishing. New England had been engaged in navigation till the war of 1812. Messrs. Francis C. Lowell, Patrick T. Jackson, and Nathan Appleton had purchased the water power at Waltham in 1813. The power loom was then being introduced into England, but its construction was a secret. Mr. Lowell had a loom made, and put in operation in Broad Street, a man turning the crank. In 1814 power looms were put in operation at Waltham, and this settled the question of the success of the cotton manufacture in New England, — the transition period was passed. But the waters of the Merrimac were still running to waste; it was not till some years later that Ezra Worthen built the mills at Lowell.

> "There was not at that time," 1821, says Mr. Treadwell, "I believe, a single steam-engine at work in any shop or manufactory in the old peninsula of Boston, and but a single one at the foundry at South Boston. There was not a lathe to be procured large enough to turn the face of an iron bed or of a platen, and I was obliged to construct these as in the Ramage press, the former of stone and the latter of wood. The inking rollers were of the English composition of glue and treacle, formed in a block-tin mould. They were the first rollers of the kind ever made in this country, and no other person obtained possession of the art of making them for eight or ten years. The first press was operated by a horse, in 1821.
>
> "After satisfying myself of the quality of the work, and that an important saving in price would be made over hand printing, but not finding the printers prepared to adopt it, I determined to begin the business of printing, and continue it until the printers should be satisfied that it would be for their advantage to adopt my press and purchase the right to use it. I built a second machine in 1822, to be operated by the same horse that carried the first. In this the bed and platen were of cast-iron, I having succeeded in adapting an old lathe to turn

their faces. In connection with two gentlemen, General W. H. Sumner and Mr. Redford Webster, I purchased type, procured workmen, and made contracts with some booksellers to print several books for them, and otherwise obtained work where I could get it. With these two presses I continued operations in Batterymarch Street, in a building owned by Benjamin Bussey, for a year or two, the work being equal to any hand-press printing, and, being performed by females at the rate of nine or ten impressions a minute, the saving of expense was important. In 1822, one of the principal booksellers of Boston purchased my establishment with the patent right for Massachusetts. It was removed to another place, and two more presses added. The establishment was burned in 1826."

During these two years many books were printed, and can be seen on the shelves of libraries, bearing the imprint on the title-page, "Treadwell's Power Press." In 1822 an edition of the New Testament from stereotype plates was printed upon this press.

It must have required much boldness and perseverance on the part of the inventor to embark in a trade to which he was not educated, with doubts of pecuniary success, the opposition of the printers, and something worse among the journeymen; for his warehouse once took fire and his presses were damaged, not without grave suspicion of those who supposed their livelihood in danger from this innovation. It may be also that the employment — now for the first time, probably — of young women and girls in press-work may have added to their fears.

The value of the Power Press was now demonstrated. In 1825 propositions came from Mr. Daniel Fanshaw, of New York, for the purchase of the presses; two of them were sent to him to be used in printing the publications of the American Bible Society and of the American Tract Society. These were soon followed by others, and after a year or more twenty presses were in operation in Mr. Fanshaw's office, with an increased profit to this enterprising printer for the first two years of ten thousand dollars a year. Mr. Fanshaw writes to Mr. Treadwell: "Your presses work well, and are the admiration of all who see them. Mr. Thomas has made no blunder as yet, and begins to understand what he would be at." The Philadelphia made steam-engines, however, seem to have given him some trouble, and his account does not reflect much credit on the mechanical skill of his assistants. "Mr. Jennings's engine," he says, "does very well, but needs close looking after. It sometimes refuses to go for ten or fifteen minutes: we then surround it, and start it again, bnt we can seldom tell how we did it. When the engine has too much or too little water, or from any other cause refuses to go fast enough, and seems inclining to a rest, the man who nurses her claps a lever to the fly-wheel, and lends her a little help, until she regains her strength and vigor."

Presses were also sent to Mr. Isaac Ashmead, of Philadelphia, for the American Sunday School work, and with them went two of Mr. Treadwell's most efficient female assistants, one of whom soon after became the wife of one of the most eminent printers in the city. In 1827 and 1828 presses were put in operation in Washington and Baltimore; these were all for book-work. It was first used for newspapers in 1829, in printing the Boston Daily Advertiser, and soon after adopted in New York for the same purpose. Many of these presses were constructed by Mr. Treadwell in Boston, and also the steam-engines and other machinery for putting them in operation. At the same time he was directing the nail manufactory at the Mill-dam.

Notwithstanding this pressure of mechanical employment, he found time to edit, with the aid of Dr. John Ware and Prof. J. W. Webster, "The Boston Journal of Philosophy and the Arts." The object of this work, according to the proposals issued in 1822, "is to render accessible to the American public the various and important information which is constantly communicated to the European world through the transactions of their learned societies and their scientific journals," and also to publish original articles relating to American science. The first number was issued in May, 1823, containing about one hundred pages, and was followed by others, once in two months, (the first volume being printed upon the Treadwell Power Press,) until December, 1826, when the patronage no longer warranted its continuance. This want of patronage "the editors feel themselves warranted in attributing to the peculiarity of the public taste in regard to works of this kind generally, rather than to the individual character of the papers which they have published, from the fact that the selected articles, which comprise the greater part of this journal, were written by men most celebrated for genius and attainments in Europe, and on subjects that have occupied a great share of the attention of the scientific world during the progress of this publication." That the journal deserved patronage, the selected articles fully prove. Its original articles by Dr. Ware, Mr. Treadwell, and others, are interesting and valuable contributions to science.

The manufacture of presses was continued until the year 1829. Mr. Treadwell says:—

> "Being from this time engaged in other pursuits, I made no efforts to alter or improve the plan of the press. Others soon came in with machines made all of cast-iron, more compact in form, and somewhat more rapid in their operation. These were preferred to my machines; and, as the printers about this time enlarged the size of their paper, my early presses were incapable of working it, and were necessarily given up."

These presses were sold for about $1,000 each. Few printers thought it advisable to invest in a single press an amount of money ordinarily sufficient to establish a complete office. Indeed, it was only in large concerns that the work required it. By the sale of these presses, with the rights to use them in several of the large cities, and the building of steam-engines to drive them, Mr. Treadwell added to his property about $70,000.

While engaged in printing, Mr. Treadwell made with the hydrostatic press used in his establishment a series of experiments on the effects of fluids under pressure on different kinds of wood placed in the cylinder of the press. A piece of dry birch weighing 47 grains was subjected to a pressure on all sides equal to 2,000 pounds on each inch of its superficies. It was found after one minute to have gained 40 grains, and its specific gravity to exceed considerably that of water. This pressure is about equal to that of the ocean at the depth of 4,500 feet.

"In another experiment the following substances were placed in the cylinder together: a mackerel weighing 4,416 gr.; a piece of the tooth of a hippopotamus, 460 gr.; a lemon, 1,320 gr.; an egg, 798 gr.; three pieces of cork, 147 gr. The pressure applied was about 4,000 pounds per inch, equal to the pressure of a column of water about 9,000 feet high; it was continued about five minutes. The mackerel was found to have lost 40 gr.; the piece of tooth gained 3 gr.; the lemon, 16 gr., and the corks 40 gr. The egg was broken, contrary to expectation, as it was thought not unlikely that the water would have passed through the shell fast enough to have equalized the pressure. The diminution of the weight of the mackerel, about one per cent, is not satisfactorily accounted for." *

In the hope of making these results of his experiments practically useful, the following communication was made by Mr. Treadwell to the Commissioners of the United States Navy.

"Boston, June 13, 1823.

"I take the liberty of laying before you an account of some experiments I have lately made, with a view of ascertaining the practicability of injecting timber with fluids, for the purpose of preserving it from decay.

"You are so well acquainted with the importance of this object that I cannot doubt that every project relating to it will receive a proper examination.

"I shall not take up your time by any review of the various schemes heretofore proposed for this purpose, as they are all well known to you. But I shall commence with the supposition that *docking*, or a thorough soaking in salt water, is the best preservative against decay now known. If timber be placed green in sea-water, or a solution of salt and water, the vessels filled merely with air no doubt take up a portion of the fluid; while the sap (which is justly considered as the great destroyer) becomes neutralized by taking a part of the salt into solution from the water which formerly contained it. These actions are necessarily exceedingly

---

* Boston Journal of Philosophy and the Arts, Vol. I. p. 578.

slow from being performed in capillary vessels of extreme minuteness, so that very small points of the different fluids can be brought in contact. From these circumstances, a period of some years is required for the sufficient docking of oak and other solid woods. . . .

"My experiments on injecting wood were made by means of a hydrostatic press (used in my printing-office) and the apparatus connected with it. . . .

"A piece of dry ash three inches in diameter and fourteen inches long was fixed to the forcing pump, so that a small part of one end was presented to the fluid as it was forced from the pump, the other part of the wood being open and in the atmosphere. A pressure of four hundred pounds per inch made the water immediately to run in a stream from the end opposite to that in contact with the pump. . . .

"The same repeated, with a piece of solid green oak. The water was forced through with the same pressure in two minutes, making its appearance by oozing, rather than in a distinct stream. In both, these specimens gained one ounce each in weight by the injection."

Several other experiments were tried with a similar result. Considering it as sufficiently proved that timber may be filled with a fluid in a very short time, if subjected to a pressure of forty or fifty atmospheres, Mr. Treadwell proposes that the government should adopt the method. It is not known that this communication received any reply; the suggestions were certainly not adopted. The plan was successfully used ten years after by French engineers.*

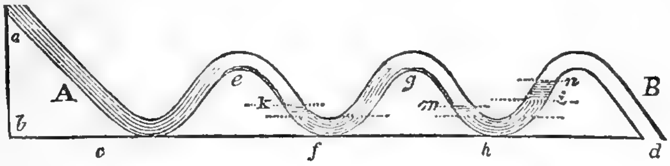
About this time, (1823,) Mr. Treadwell's advice was asked as to a question of hydraulic engineering, the result of which shows well his method of reasoning and his ready resources. A leaden pipe, an inch and a half in diameter and about six thousand feet long, had been laid to supply water for the families of the workmen of the Mill-dam manufactories. It was laid principally in a marsh, and ran beneath the bed of two creeks about twelve feet deep each. The end of the pipe at its outlet was about four feet below the level of the source. When completed, not a drop of water would run through it.

"In this state of things I was requested, by those interested in the aqueduct, to consider the circumstances, and endeavor to procure a passage of the water. When the exact condition of the aqueduct was taken into consideration, I perceived that the water let into it might have made such an arrangement in relation to the air with which the pipe was previously full, as to obstruct wholly its passage. For let us suppose, in the annexed figure, A B to represent a

---

* A process of injecting corrosive sublimate was reported by Kerausdren, in 1839. Kyan also devised a process called *Kyanizing* for injecting the same substance; since 1848 it has been used in this country, and found to be very effective. In a letter on these various processes, James B. Francis, Esq., of Lowell, states that, "about forty years ago, Bethel devised the process called *creasoting*, in which a fluid derived from the coal tar of the gas works is injected. This is very generally used in England for the preservation of railroad ties, and is considered very efficacious." Various other methods for the same object are now in use in Europe and in this country. See "Mémoires Ponts et Chaussées," Vol. XI., 1836 and 1843.

pipe open throughout its length, but its sides being perfectly tight, and having the several vertical flexures here represented; and let it be required to pass water, or any heavy fluid, through it in the direction A to B, the end A being elevated the distance $a\,b$ above B; $c\,d$ being a horizontal line. It is evident that the water, being let into the end at a, will pass and fill the pipe to e, displacing all the air with which the pipe, being open to the atmosphere, was previously full. Flowing over the curvature e in a stream or column less than the base of the pipe, it fills the curvature at f without displacing the air previously contained in the descending section from e to f. This air is thus shut up, and cannot pass from the pipe in any direction without passing under the water, which, from its inferior specific gravity, is impossible. The water, continuing to flow over the flexure e, rises from f to g, and, flowing over the flexure, the same thing is repeated as to the air from g to h which took place at the flexures e and f; rising from h until it reaches some point, i for example, at which the sum of the perpendicular heights of the ascending columns $c\,e$, $f\,g$, etc. are equal to the height of the column $a\,b$. . . . That is, if we suppose the air to be unelastic and void of weight; but as this is not true in fact, the air will be condensed in a greater or less degree, according to its volume and the height of the columns of water opposed to it. In consequence of this condensation, the water will rise, as shown in the figure, to k and m, for example; and the weight of these columns, being added to the effective force of the column $a\,b$, produces a rise of the water to some point n in the flexure $h\,n$. There is then a perfect equilibrium in the opposing forces, and the water can flow no farther.



"As the aqueduct at the Mill-dam was more or less bent through its whole course, the flexures being considerable at the creeks under which it passed, it appeared to me certain that it was partly filled with air, and that this alone interrupted the flow of water. On opening small holes into it in several places, air rushed out in great quantity; still, however, the water did not flow at the reservoir, and, as it was impossible to get at the bending in every part of the pipe without the labor of uncovering it wholly, this design was abandoned. A forcing pump was then coupled to the upper end of the pipe, and water which had been heated in the worm-tub of a distil-house in the vicinity, was forced into it. The pump was furnished with a valve loaded with a weight equal to a column of water eighty feet high, and a very small opening made into the reservoir at the mills, so that the water, passing slowly through the whole length of the aqueduct, was there discharged. The object of this apparatus was to produce an absorption of the air, by bringing it in contact, under heavy pressure, with water which had parted with some of its air by being heated; as these conditions are known to be favorable to the absorption of air by water. The pumping was continued about ten days, and the quantity of water may be taken at about twenty hogsheads. The pump was then taken off, and the aqueduct opened into the fountain. The water was now found to flow at the reservoirs, discharging as much as was due to the head, and continued to flow uninterruptedly." *

---

* Boston Journal of Philosophy and the Arts, Vol. II. p. 493.

"On the 12th of November, 1823," says the Autobiography, "I was elected a Fellow of the American Academy of Arts and Sciences, and there it was my good fortune first to meet Dr. Bowditch, then in the full maturity of his reputation and power. He at once extended to me his friendship, and poured out his thoughts to me with the utmost freedom. This friendship continued, and was often exhibited, through the remainder of his life."

Mr. Treadwell continued an active member of the Academy through life, and was elected to most of its important offices. He was Recording Secretary from May, 1833, to May, 1839; Vice-President from May, 1852, to May, 1863; and a member of the Rumford Committee from January, 1833, to May, 1863. This Committee — the most important in the Academy — is elected annually to carry out the intentions of Count Rumford, who, in 1796, presented to the American Academy five thousand dollars, "to the end that the interest of the same may be by them and by their successors received from time to time, forever, and the amount of the same applied, and given once every second year, as a premium, to the author of the most important discovery or useful improvement which shall be made and published by printing, or in any way made known to the public, in any part of the continent of America, or in any of the American islands, during the preceding two years, on heat or on light; the preference always being given to such discoveries as shall, in the opinion of the Academy, tend most to promote the good of mankind."

The Boston Mechanics' Institution was founded in 1826 for "the encouragement," in the words of the Constitution, "of a taste for the fine arts, and the exact sciences among our operative mechanics and workingmen, as well as others." Dr. Nathaniel Bowditch was elected President, January 12, 1827, and Mr. Treadwell the first of the three Vice-Presidents; and on the retirement of Dr. Bowditch, in 1829, Mr. Treadwell was chosen President. A valuable apparatus and various models were purchased by a subscription promoted by the example and influence of Dr. Bowditch and others. In 1827, Mr. Treadwell began a course of lectures on practical subjects, especially the steam-engine, particularly adapted to the wants of the workingmen of Boston. These courses, and others upon subjects connected with the objects of the Institution, were repeated for several years, with much success; the introductory lecture to the course for each year was delivered by a gentleman of commanding talents, and, when possible, of high public station. Among these were Daniel Webster, Joseph Story, and Edward Everett.

The following letter from Mr. Justice Story, of the Supreme Court of the United States, to Mr. Treadwell, as President of the Institution, indicates the interest taken in the improvement of the mechanics of Boston.

To DANIEL TREADWELL, ESQ.

BOSTON, April 22, 1830.

Dear Sir, — I have the pleasure to acknowledge the receipt of your letter, and the check of forty dollars in behalf of the Mechanics' Institution which was enclosed in it. Allow me the favor to return the check, with the request that the Institution will be pleased to apply the amount towards the increase of their apparatus.

No man can be more sensible than myself of the deficiencies of my introductory discourse. But the kind terms in which you are pleased to express the satisfaction of the Institution with my effort is truly grateful to me, and would, under every circumstance, afford me the sincerest consolation. I beg to add that I shall ever esteem it a fortunate occurrence to have connected my name with the admirable objects of the Institution. Wishing it and yourself every success, I have the honor to remain, with the highest respect, your obliged friend,

JOSEPH STORY.

On resigning the office of President, in 1881, Mr. Treadwell received the following acknowledgment of his services.

To DANIEL TREADWELL, ESQ.

BOSTON, April 26, 1831.

Dear Sir, — I have the honor to inform you that the following vote was passed unanimously at the annual meeting of the Boston Mechanics' Institution, held in the lecture-room of the Athenæum on Monday evening last: —

" *Voted*, That the thanks of the Institution be presented to Mr. Daniel Treadwell, for the valuable services which he has rendered to it during the last two years in the office of President."

Allow me, sir, to add an expression of the pleasure I feel in communicating a vote, the sentiments of which are so much in accordance with my own.

With great respect, I have the honor to be your most obedient servant,

F. C. WHISTON,
Recording Secretary B. M. I.

In 1838, when the Massachusetts Charitable Mechanics' Association was founded, all the apparatus belonging to the Boston Mechanics' Institution was transferred to it, and the latter ceased to exist.

While still continuing the manufacture of his printing-press, and superintending the nail-machines on the Mill-dam, Mr. Treadwell, on the 11th of March, 1825, was appointed by the Hon. Josiah Quincy, Mayor of Boston, acting in behalf of the Board of Mayor and Aldermen, " a *Commissioner* to ascertain the practicability of supplying the city with good water for the domestic use of the inhabitants, as well as for the extinguishing of fires, and for all the general purposes of comfort and cleanliness."

At that time the only water supply for the city was obtained from wells, from Jamaica Pond through a wooden pipe about four inches in diameter, and from rain-water collected in cisterns from the roofs of houses. The quantity of water required daily was estimated by Mr. Treadwell at 100 gallons for each family, and 500,000 gallons for other purposes. This was about the proportion of the London supply at the time. There were then 50,000 inhabitants collected in 8,000 families, and the daily supply proposed was 1,600,000 gallons. To provide against an extraordinary demand in case of fire, reservoirs within the city were to be kept full, and during the emergency the use of water for other purposes diminished. The Beacon Hill Reservoir was to be of 1,800,000 gallons' capacity, sufficient when two thirds full, which it would be during most of the night, to supply twenty good engines operating constantly ten hours.

"Various sources in the neighborhood of Boston, from which 1,600,000 gallons or more daily may be obtained, were examined. Two of these, Charles River above the falls at Watertown, and Spot Pond, in Stoneham, appeared to have advantage over all others. The supply from the river, at all times abundant, must first be raised by artificial means before distribution. The pond, 140 feet above tide water, is sufficiently high to reach all parts of the city; the water of both is of good quality." From the river, the water is brought, in Mr. Treadwell's plan, in two trunks of thirty inches in diameter, to the Mill-dam, where it is pumped through iron mains to reservoirs on the highest points in the city, and thence distributed. The advantage of such reservoirs is strongly urged, not only as equalizing the distribution, but also, inasmuch as water will be flowing into them night and day, in the less diameter of pipes required to supply the 1,600,000 gallons in twenty-four hours, and in addition furnishing a more perfect and ready supply in case of fire, or in case of any accident to the mains external to the city. The water from Charles River, according to this plan, is first let into a settling reservoir of five acres in area, and thence into the mains, which deliver it to the pumping engines at the Mill-dam. From Spot Pond, "after the supply shall have been proved to be sufficient," it is proposed to lead the water through an iron main by one of two courses, either by crossing the river at Craigie's Bridge, or by the Mill-dam, to a reservoir on Beacon Hill. The cost of bringing water from Charles River and distributing it through all the streets laid down in Hale's "Survey of Boston," 116,190 feet, is estimated at $514,842. An equal quantity from Spot Pond with its distribution, it is estimated, will cost $558,353 or $615,469, according to the route adopted. This report of thirty-two pages, with detailed estimates, was made on the 4th of November, 1825. No action was taken with regard to the proposed plans, except a reference to the next city government. The impression seems to have been that the time had not yet arrived when so large an outlay as $500,000 was advisable. Had the Charles River plan been adopted at the outset, and secured from all contamination or diversion, we have good reason to believe it could have been made to supply all the pure water that would have been needed in the city for the fifty years following Mr. Treadwell's report.*

In 1833, on the election of General Theodore Lyman, Jr. to the Mayoralty, Mr. Treadwell addressed to him the following letter: —

> "Sir, — In the year 1825, I was employed by the city government to examine the ponds and rivers of this vicinity, for the purpose of determining whether it would be practicable to supply the inhabitants with good and wholesome water for all the purposes for which it might be required. After a full examination of the subject, I submitted a report to the Mayor and Aldermen, in which it was shown that it was perfectly practicable to obtain and distribute through all the principal streets a full supply, and that at a cost not exceeding $600,000 in the outlay. Since that time the attention of the City Council has been called to the subject occasionally by the Mayor, and committees for investigating it have been several times appointed by successive Councils. So far as I am acquainted, all of these have acknowledged the importance and the practicability of obtaining a good supply of water, but none of them have made anything like an earnest and vigorous effort to accomplish it. Perhaps the short period for which the members of the municipal government are elected has an unfavorable influence upon efforts for this purpose. People are not naturally disposed to enter ardently upon projects while possessed with a fear that they may never be permitted to accomplish them. Without stopping, however, to inquire why nothing has been done to supply our city with water, let us turn to what it may now be expedient to do for this purpose. To this end, sir, I take the liberty, at the moment of your election to the first magistracy of the city, to present to you a statement of some of the principal advantages which the city could derive from a good supply of good water, with no small confidence that, if your attention becomes fixed upon them, you will commence and continue unremittingly in an effort to obtain them. It is unnecessary to cite to you the argument or authority derived from the almost universal practice of the cities of Europe, both in remote and in present times, to supply themselves with water by aqueducts from some great external source.
>
> "To that class of people, however, who see in the present too much disposition to innovation and scheme, it may not be useless to state that this project is warranted by the example of the oldest cities, and has been followed by others in succession to the present time. The practicability of obtaining for Boston a sufficient supply of water for all purposes is not to be doubted, whatever difference of opinion there may be as to the best mode of obtaining it. The great question is that of expediency, and this may perhaps be best resolved by considering it

---

* The quantity of water passing the Waltham mills was estimated at a steady flow of 40 cubic feet a second, or over 26 millions of gallons daily; a subsequent, more careful examination made the flow, in the months of August, September, and October — the three driest months in the year — equal to 30 millions of gallons daily. In 1886 the daily supply to the city was 36 millions; the highest, 41 millions.

in this form. Can it be shown that a saving in money would result from the construction of water-works for the supply of the city?

"Let us inquire what is paid for the insufficient and uncertain supply of water now obtained by the inhabitants. This is from three sources, — wells, cisterns holding rain-water as collected from the roofs of houses, and the old aqueduct from Jamaica Pond. There are in Boston 7,000 inhabited houses, or very nearly that number, and it may be taken that there are 2,400 wells, or a well to every three houses, each well having upon the average two pumps. The average cost of these wells with their pumps, taking their average depth at forty feet, will be $160 each, amounting in all to $384,000. The number of cisterns may be taken at 1,800, or one for every four dwelling-houses, and with their pumps they may be taken to cost $70 each, making an aggregate cost of $126,000. Thus the cost of wells, pumps, and cisterns amounts to $510,000. As this sum has already been expended, it cannot now be redeemed or taken from them, and it is arrayed in this form merely to show that the amount estimated for the cost of waterworks does not much exceed that already expended for the wells and cisterns, and that the capital required to furnish water in this way for every new house erected, being not less than $150, any one would prefer paying $9 yearly for a supply of water rather than to form a well and cistern for himself. The yearly cost of keeping a pump in working order may be considered as 50 cents, or $2,400 for the pumps of Boston. But a pump will decay, and must be replaced in twenty years. We have then 4,800 pumps at $40 each, or $192,000, to be expended every twenty years, giving $9,600 a year. The yearly cost of the repair of cistern pumps, and the sum expended in rebuilding those which decay, may be taken at half that expended on the pumps of wells, which we have seen above is $2,400 + $9,600 = $12,000. Add for yearly expense of cisterns $6,000, and we have $18,000 for the yearly cost of maintaining the pumps and cisterns of Boston. Let us next examine the saving in the premium of fire insurance. The official valuation of the real estate of Boston is 40 millions. Deduct from this one third for the value of land not subject to destruction, and it leaves $26,660,000. The personal estate is valued at 28 millions, but as this includes property vested in banks and other stocks, vessels, and a variety of other property not subject to ordinary fire risks, we may consider the personal property subject to insurance against fire at half the above sum, or 14 millions. We have then a property of at least 40 millions on which insurance is actually paid or assumed to themselves by the owners. The average rate of premium on this property is not less than 40 cents on $100; consequently it amounts to $160,000 a year. It will, I believe, be admitted, by most persons acquainted with the subject, that, if the city were abundantly supplied with water, the rate of insurance would be reduced one quarter part; consequently, there would from this be a saving annually to the citizens of the sum of $40,000. This, added to the $18,000 before enumerated as the yearly cost of pumps and cisterns, gives $58,000 annually which would be saved to the city by sufficient public water-works. I have not taken into the preceding account the amount paid by the portion of the citizens who receive water from the aqueduct from Jamaica Pond. Neither have I considered the saving which would result from the diminution of the expenditures of the fire department. These and perhaps other considerations may be neglected, as the $58,000 already specified is sufficient to pay the interest on the cost of almost any plan of water-works which may be adopted, together with the cost of keeping them in operation. Is there then any reason for delaying a work of this kind? Will it be said that the expenditure of a million is beyond the means of the city, or that the health and comfort produced by such an expenditure will not be an equivalent for it? What is the amount of health and comfort derived to the citizens from the possession of the Boston Common? Many of them do not see it three times in a year, and yet the man can hardly be found who would advise that it should be sold, preferring to place the money that would be obtained for it in the public treasury to the enjoyment of it in its present form. But the sale of one half of the land of the Common will produce a sum sufficient to supply the city with water, and it is not unwarrantable to assume that, if the city was possessed of complete water-works, and the citizens were called upon to relinquish them or the possession of the Common, they would prefer giving up the latter as the less valuable of the two.

"The present prosperity of the city gives the means and energy for prosecuting the subject rarely possessed in any period. No advantages can arise from delay, but, on the contrary, changes are constantly taking place which make its execution more difficult. In proof of this, I will state that in 1825 power might have been obtained on the Mill-dam for raising the water of Charles River to the city. This power since that time has been taken for other purposes, and cannot now be obtained. It was then proposed to the city government to bring the water of Charles River down the south bank of the river to the Mill-dam, and thence to raise it to the elevated parts of the city. Now the south bank of Charles River is partly occupied by the Worcester Railroad; which will be a serious impediment in the way of executing the project as then designed, and other circumstances of like kind might be adduced. Having thus, sir, stated in a hasty and imperfect manner some of the facts connected with this subject to call your attention to it, if, indeed, it has not already been fixed upon it, I know that you will not dismiss it without a further investigation of its merits, and I will not suffer myself to doubt for the result."

In the following January, 1834, Mayor Lyman sent a communication to the City Council, urging an immediate consideration of the subject of introducing water into the city, enforcing it with extracts from Mr. Treadwell's letter, and from his report of 1825.

On the 20th of March, 1837, Mr. Treadwell was again chosen by the City Council the first of three commissioners to re-examine the sources and the best method of supplying the city with pure water. The population had doubled in the last twenty years, and in the last seven years the increase had been even more rapid than in any equal preceding period; it had reached 80,000. On the supposition that in five years the population would be 87,000, and in ten years 105,000, provision was made by the commissioners for an immediate supply of 1,600,000 gallons daily to be increased in five years to 2,500,000, and in ten years to 3,000,000 gallons. Twenty sources of water were examined, and of these Spot Pond, Long Pond (Lake Cochituate), Mystic Pond, and Charles River were alone deemed suitable. The route, construction, and cost of supply from each of these is given. A majority of the commissioners, including Mr. Treadwell, were of opinion that the Spot and Mystic supply should be adopted, with a combined system of pumping and gravitation through iron pipes; the minority recommended that from

Long Pond, by gravitation only, in a brick conduit to Corey's Hill Reservoir. Two reservoirs within the city, as in Mr. Treadwell's first report, were recommended as especially useful, in case of extensive fires, or of accident to any of the connections external to the city.

In December, 1838, at the request of the water committee, a revised report by the same commissioners was made, in which the two plans are again considered, and that from Spot and Mystic Ponds combined, as advocated by Mr. Treadwell, is again recommended, with a supply of 28½ gallons daily to each inhabitant. These two independent sources were believed to have great advantages over a single source, through a single conduit, from Long Pond; the estimated cost of the first was $839,806; that of the other, $1,060,484. In the report written by Mr. Treadwell, the commissioners say: —

> "In expressing this opinion, they are not insensible to the great excellence of the supply which is proposed as the alternative. Long Pond, as we have already stated, is capable of affording an ample and permanent supply of pure water. It is of sufficient elevation to admit of its water being brought to the neighborhood of the city, by a simple aqueduct, to a reservoir of such height that it may be distributed therefrom to every part of the city. This may be done without the attention required by works for pumping. By the aqueduct proposed to be constructed, a copious stream of pure water would be at once brought to the vicinity of the city sufficient for the wants of the inhabitants for a long period to come. It would be a work which, when completed, the inhabitants might well regard with pride and satisfaction, and such as the commissioners would not hesitate to recommend, were they not firmly of opinion that all its material advantages may be obtained by works somewhat less imposing, yet less expensive, and in some degree more entitled to confidence in their permanency."

To Mr. Treadwell we owe the first of a series of examinations and reports, which led to the construction of the great Water-Works opened in October, 1848. To these works additions have been made as the demands increased, until they deliver on a daily average thirty-six millions of gallons, by a combination of the two systems recommended in the first report, by pumping and gravitation, much of it derived from two of the available sources, Mystic Pond and Lake Cochituate, there pointed out, and producing an annual revenue of over one million of dollars.

Of the importance of more than one source of supply, and of reservoirs within the city, Mr. Treadwell never lost sight, and in 1870, in an article published in the Traveller, he says: "It may be well for the city authorities charged with the responsibility of deciding the question of discontinuing the Beacon Hill Reservoir, not to destroy it until they have a little more experience of elevating the water supply by steam-pumping, say one hundred and thirty feet above the level of the

Beacon Hill Reservoir." And again, in 1871, then in his eightieth year, in an article in the Daily Advertiser: "It is to be hoped the present panic concerning a water famine in Boston will not pass away without teaching the people the temerity of trusting to a single source of supply, especially when that supply depends upon a complicate system of tunnels and reservoirs, pipes, pumps, engines, and gates distributed through twenty miles, and requiring the constant attention of competent engineers and faithful operatives." That these warnings were not without reason, it may be remembered that in the following November, during a severe frost, the whole supply of water for the city was for several hours cut off. The reservoir was empty; the possibility of a conflagration caused great alarm, and the fire-engines were hurried to the wharves. Fortunately no fire then occurred; but during the great fire of November 9th and 10th, 1872, when the supply of water from the mains was insufficient for the great demand, and many engines stood idle, the city reservoir, which might have done good service, was empty. Three independent sources of supply, and as many large mains, with the pumping station for the high service, have since been constructed, and the Beacon Hill Reservoir safely dispensed with. Those at South Boston and East Boston, as originally intended, are still kept full in case of accident to the supply mains.

In 1827, attention was drawn to the construction of railways in New England. The first railway charter in Massachusetts was granted on the 4th of March, 1826, to the Granite Railway Company, for the transportation of granite from the quarries in Quincy to tide-water in Neponset River. The company combined the management of the quarries with that of the railway, and among its first business operations was the furnishing of stone for the Bunker Hill Monument. The road is still in operation. About the same time numerous routes for railways were surveyed, — the Boston and Lowell, Boston and Providence, and that to Albany. On all these roads the transportation was to be by horse-power. This was the method already adopted in England, and in this country on the Baltimore and Ohio, and the Mohawk and Hudson; all the discussions as to their construction were based on this plan.* Railways in England and in the United States had all been constructed with double tracks; they were considered indispensable.

---

* By the charters of the Massachusetts roads, any person had the right to use them who should comply with the rules of the directors; but as they had, by the charters, full control over "the transportation of persons and property, the construction of wheels, the form of cars and carriages, the weight of loads, and all other matters and things in relation to the use of the road," individual rights were lost.

Mr. Treadwell originated and matured the plan of conducting traffic upon a *single track,* — a plan that has resulted in an immense benefit to this country, and must be regarded as a main cause of the greater success and efficiency of its railways, as compared with the English.

> "In the year 1826," says Mr. Treadwell, "I arranged in my own mind the method of conducting the transportation in both directions upon a single set of railway tracks, by collecting the cars in trains, starting at fixed times, and meeting and passing at determined points upon the road, and made the plan known to Mr. Nathan Hale and the late David Moody, in the autumn of the same year. My first printed notice of it was dated the 22d of August, 1827, and is published in the 'Franklin Journal' for October. In 1828 I gave two lectures before the Boston Mechanics' Institution upon railways generally, and in one of these lectures I fully developed my plan, showing, by apparatus contrived and made for the purpose, trains moving upon one set of tracks in different directions, and with three different velocities."

In the winter of 1829 the Massachusetts Railroad Association was formed. Mr. Treadwell introduced this mode of transportation at an early meeting, and was appointed, with two others, a committee to report upon it. The report, "On the Practicability of conducting Transportation on a single Set of Tracks," was written by Mr. Treadwell, as Chairman of the Committee, in May, 1829. The following extracts from the report sufficiently give his argument for a single track: —

> "The advantage of a double set of tracks over a single set appears to your committee to be confined to a single object, namely, to enable carriages moving in opposite directions to pass each other freely; and, except in this particular, a double set of tracks can have no advantage over a single set save the very trifling one of their being less worn by the action of the wheels upon them. As, however, a railway is injured more by frosts and rains, and by natural decay, than by absolute wear, and as the injuries from these sources will be proportionate to the quantity of material exposed, it must be evident that the cost of repair will be much greater for a double, than for a single set of tracks. . . .
>
> "Your committee believe that there is a mode by which carriages may be made to pass each other, on a single set of tracks, without the least difficulty or hindrance. The mode by which this may be accomplished is in prescribing certain periods for the entrance of the carriages upon any part of the railway; and by providing that every carriage so entering shall be moved with such velocity that it shall arrive at a certain fixed distance within a prescribed time. . . .
>
> "The only objections which have been urged against this method of conducting transportation, which seem to demand a serious attention, are these: 1st, the liability to hindrances from a neglect of the prescribed velocities, or the impossibility of observing them; and 2d, the inconvenience that would arise from not being permitted to commence a journey at any moment of the day.
>
> "With regard to the first of these objections, the committee would observe that there is no mode of transportation known, perhaps none to be discovered, in which the certainty of passing a given distance within a given time is so complete as that procured by means of a railway.

With the exception of a very small portion of the year, when it may be covered with deep snow, this structure is altogether beyond the reach of those changes which affect common roads, canals, and rivers. The resistance to the moving of loads over it is at all times alike; so that the load which an animal can draw upon it one day may be drawn on all other days, and this, being once known, may forever after be relied upon. As this system of conducting transportation will necessarily bring large trains of carriages together, sufficient assistance would always be at hand to remedy any ordinary disaster which might occur to the railway, or to a carriage. To allay all apprehension, it might even be ordered that one of the carriages of every train should carry such pieces of machinery and tools as might by any possibility be required to repair either the railway or carriages. Should a carriage be broken beyond the power of repair, its removal from the railway would, by the united labor of all the conductors, be immediately effected. The disabling of a horse would be of no serious consequence, as his load might be easily distributed amongst the other horses of the train.

"To show the certainty with which journeys may be accomplished in given times, even upon common roads, the committee have only to call the attention of this Board to the arrival of the United States mail at the various post-offices. The failure of a mail from a distance of two hundred miles is known to be a rare occurrence. When the roads are in good order, it may be said that it never happens; and yet the liability to hindrance upon a common road, in the best order, is much greater than upon a railway at any season, except immediately after a deep snow. . . .

"With regard to the second objection, namely, the inconvenience that would arise from not being permitted to commence a journey at any moment; the committee cannot believe that any one will, after a careful examination, consider it of much weight. All who travel by coaches are now subject to the same inconvenience, if it be one; for all coaches start at fixed hours. Yet we never hear it urged as an objection to the system of stage-coach travelling that their departure is thus limited.

"So on a railway, even if it were open at all times, the public coaches must necessarily depart at fixed periods, and the travelling must be performed in the public coaches; for who would keep a private vehicle for this purpose? . . .

"It is proposed, in the Report of the Board of Directors of Internal Improvements, that, to provide for swift carriages to pass those moving at a slow rate, cross rails shall be laid at distances of one eighth of a mile through the whole route from Boston to Albany, by which a coach may pass from one set of the main tracks to the other, and thus avoid any carriage which may be moving in the same direction, but at a lower velocity. The committee are acquainted with no method of providing for the passing of carriages, under the conditions here stated, less objectionable than that thus proposed; and yet they apprehend that this will be attended with vexations and danger. There is no mode, at least none known to your committee, by which sidelings or branches can be united to a main track so that considerable care shall not be required, not only in passing from one to the other, but in passing along the main track alone, at every point where a branch is united with it. To pass in safety, the ordinary speed of coaches must be reduced, and in the night-time lights will be required. Now, as these sidelings must be formed, according to the Commissioners' Report, at distances of one eighth of a mile, no less than one thousand five hundred and eighty-four must be passed in the course of a railway extending from this city to Albany. . . .

"In closing their report, your committee will state that they are decidedly of opinion that a single set of tracks, thus used, will offer greater facilities to transportation of every kind, and be of greater public utility, than a double set used in the ordinary mode. They are aware that this is a bold, perhaps it will be said a rash avowal. But as the opinion has been deliberately formed, the committee do not hesitate to declare it thus frankly and explicitly. All of which is respectfully submitted."

The plan proposed did not meet with favor. It was stoutly opposed at the Board of Directors, and by a committee to whom the report was referred. This committee, in a long counter report, declared it "impracticable to collect at the station so many people with their baggage, to start at a prescribed time, to move with a prescribed velocity, to pass over a prescribed space, and arrive at a prescribed minute, like the movements of a machine; that the effect of this system will be to bring all persons who use the road into trains or caravans, which shall move majestically on, and by their united strength and influence the weak, lame, and unfortunate will be sustained, and all accidents set at defiance. Whether all the concourse of people are to be fed upon the road, or marched into some great hall for their meals, is not explained; that they must be kept in their ranks in some form or other, and a prescribed form to feed provided, seems to be a necessary part of the system." It was estimated that "the number of cars required would occupy 2,660 feet, making a line of carriages and horses more than one mile and an eighth in length when arranged close together." It would involve delays and great loss of time, not only in starting, but throughout the whole line; delays which would be increased by the fact that the amount of freight will be greater in one direction than in the other, and require a corresponding difference in velocity. The plan, it was said, "may be true in theory, but in the opinion of your present committee it is of that kind of theory which cannot be reduced to practice." It had not been tried in England where are many railroads, nor is it mentioned in any book on the subject. "No citation is given to show that anything was ever thought of which would bear a comparison with that part of the new system called regulated velocities, and, if we understand it rightly, nothing in the whole range of human affairs *can* ever be thought of to which its application would be so ruinous and destructive as to the very railroad (the Boston and Albany) now under consideration." The only proper mode of construction, in their opinion, "is a double set of tracks with well constructed joining places from one set to the other within fifty or sixty rods of each other." In support of this statement they can, they say, cite the experience of the best English railways.

This report was followed by Mr. Treadwell with another, in which he explained still more fully his plan of the collecting of carriages in trains, with fixed times of starting, and moving with regulated velocities, so that the meeting and passing shall be at certain given points, often many miles asunder; and showed that even double tracks would require distinct works in the form of frequent and sufficient passing places from one set of tracks to the other. In this the sideling or turn-out is formed in part by a portion of the track appropriated to carriages of an opposite direction, but nothing is gained over the common sideling. As to the difficulties and delays in commencing the journey, "we have only to say that to accommodate passengers coaches must be provided, and the passengers must by some means be brought to take their places in them. Whether this is done in a short or long period, the difficulty attending it must be, in the opinion of the committee, very much the same in amount. For it certainly cannot increase the labor of a passenger in taking his place in the coach to have another passenger doing the same thing at the same time. If the usage of the best conducted vehicles in the world, namely, the London mail-coaches, may be thought of authority, it is in this particular in favor of the plan recommended. For it is well known that all the mail-coaches of that metropolis leave it from the same spot for all parts of the United Kingdom at a single hour in the day only. The remark that there is no authority to be found in the English roads for single tracks has no bearing whatever upon the question. For the system of regulated velocities and times of entrance has been but lately proposed. It has never to our knowledge been practised or attempted in England. This is so essential to the success of a single set of tracks, that without it the present committee would not for a moment recommend their adoption. It must not be forgotten that a railroad is an instrument of transportation, and that the amount of income received from it, compared with the cost of structure, will be the best possible measure of success. It may be safely assumed from the estimates made for the road from Boston to Providence that the single track will not cost more than 52-100ths of a double set, and if the traffic upon the former should exceed 52-100ths of that upon the latter at the same rate of toll, then it is evident that the single set of tracks will be a more profitable work than the double. The cost of maintaining the road in good condition is very nearly in proportion to the amount of track exposed. The double track has nearly twice the quantity of rails, spikes, and keys exposed to rust, and nearly twice as many sleepers, and a much larger amount of bridging exposed to rot and decay, and nearly double the amount of road-bed exposed to storms and frost. These taken together make a great item in the yearly cost of railroads — a most serious drawback upon the profit."

This report drew forth another counter report. It was again reported that the plan is impracticable. "It is not the single set of tracks alone of which we complain, but the restrictive system in which they are confined. Restriction and embarrassment in our intercourse is the theme of our complaint."

With the exception of Mr. Nathan Hale, editor of the Boston Daily Advertiser, and Mr. David Moody, an eminent mechanic, no director of the Association was in favor of the plan. Mr. Hale, who saw its advantages from the first, was President of the Worcester road, and modelled it upon the principle indicated and explained in Mr. Treadwell's ingenious paper. Mr. Patrick T. Jackson did the same for the Lowell, of which he was President; it was also adopted by the Direction of the Providence road. These roads were opened for travel in 1834.

In the month of October following the publication of these reports came the great competitive trial of locomotives at Rainhill, on the Liverpool and Manchester Railway, for the prize of £500, offered by the directors "for the best locomotive engine which should, on a certain day, be produced on the railway," and, if of six tons' weight, draw after it day by day twenty tons' weight (including the tender and water-tank) at *ten miles* an hour, with a pressure of steam in the boiler not exceeding fifty pounds to the square inch." George Stephenson's "Rocket," which weighed only about four tons, met the prescribed conditions and received the prize. It eclipsed the performances of all locomotive engines that had been constructed, and at the same time established the superiority of the locomotive for the working of railways. This motive power was adopted here, and with it Mr. Treadwell's plan of fixed times and regulated velocities.

Writing many years after, he remarks: —

> "It may be said that the use of steam necessarily collected the carriages in *trains*, and this being done, everybody would at once perceive that a single track might be used, after the American manner. Now this is so far from being the case that the method has not been adopted anywhere in England or on the Continent, though millions upon millions might have been saved by its use, and all the travel and intercourse upon half the roads of England carried on as perfectly as they are now. A single case may be cited to show that the English engineers are not yet possessed of the knowledge of our system, or that it does not influence them in the plans of their works. The great tubular bridge at the Straits of Menai has been constructed double, that is, two tubes or bridges have been thrown over the Strait, one for the up, and another for the down trains. Now it is evident, as the length of the bridge is less than 2,000 feet, that it would have been the easiest thing in the world to have arranged the travel in the two directions, so that any meeting of trains at the Menai bridge should have been, if not impossible, at least so certain not to happen as to be practically quite out of the question. Had this occurred to the mind of the engineer, and been acted upon by him, it would have saved the company at least a million of dollars. It cannot be said that this sum was of small consequence to the company, because the whole road has been a most unfortunate speculation, the stock before its completion selling at seventy per cent discount.

"Upon any route where the traffic does not require such frequent trains as to make a single road insufficient or unsafe, (for the double track is required to accommodate *frequent trains* rather than a great amount of traffic,) it must be as good for the public as a double one, and more profitable for its stockholders, even if the cost of building the latter were no greater than the former; or, in other words, most of the single roads of Massachusetts at this moment are more valuable than they would be if made double without cost to their owners; or, if the government would offer to lay down a second track upon such roads without expense to the proprietors, upon condition only that the proprietors would conduct their business upon the double tracks, and keep the whole in repair, it would not be for the interest of the proprietors to accept the donation, because their income would be no greater, their running expenses no less, while the repairs would be so much enhanced as to affect materially the net income from which the dividends are made.

"The whole of this leads to the unavoidable conclusion, that, if the proprietors of the Chester and Holyhead Railroad, for example, would break up one of their tracks and tumble one of their tubular bridges into the Straits of Menai, their property would be more productive than it is as it now exists, or they would be in the way to receive dividends sooner than they will if the whole be preserved. Does not this go to account for the greater profits obtained from the New England than from the European railroads, and the superiority of the system upon which they have been planned and constructed?

"With the exception of the single track and the *wooden* sleepers (or *ties*) no considerable improvement has been made upon railways or the machinery connected with them in the United States. Some changes have been made by us in locomotives and cars, and there have been improvements in the sense of adapting them to our condition and modes of intercourse, but they have not to any great extent affected the great system of railway locomotion. The wooden sleepers were adopted purely to save the greater cost of stone, and without any foresight of the superiority which is proved to be inherent in them."

In June, 1851, the Hon. Nathan Hale, in an article on American Railroads in the Boston Daily Advertiser, of which he was then editor, compares these roads with the English roads, and shows that the progress of this improvement has been more rapid and more successful in this country than elsewhere; that the cost of construction and management has been less, and the return to the stockholders much larger. In 1849, the aggregate length of the nine principal railways in England was 2,258 miles, built at a cost of $217,000 a mile; from these the average dividends paid the shareholders was less than three per cent, the other railways, equalling these nine in length, paying less, and some of them nothing. Comparing small things with great, it was shown that, at the same time, of the 613 miles of railroad in Massachusetts (238 miles of double track, and 375 miles of single), costing about $53,000 per mile, more than half paid, in 1850, an average dividend of eight per cent from the net profits of the year, and the average dividend paid on all the roads exceeded seven per cent, each company having retained a greater or less reserve. This was done notwithstanding the far smaller amount of population in proportion to the territory accommodated than in Great Britain, and with less than one fifth of the number of passengers per mile conveyed on the principal lines of railroad.

> "The obvious cause," says Mr. Hale, "of the greater success of these works in this country is their comparative cheapness. But another question arises, What is the cause of this greater cheapness? A reply which may be naturally given to this inquiry is the inferiority of the works. Such a reply would doubtless be to a certain extent founded in truth; yet to a very limited extent only, so far as the perfection of the respective works is to be measured by their adaptation to the objects designed to be attained in each case. To a certain extent it may be admitted, in regard to the general character of these works, including even those which are most thorough in their construction, that they are inferior in their style and finish, so far, at least, as embellishment is concerned, and often the permanency of their structure. In some of these cases this course was consistent with a judicious policy, as a choice between attaining an object in only an imperfect degree instead of being deprived of it entirely. Of most of the works, however, it may be said that, in the degree of finish and permanency of their structure, they are adapted to their purpose, and this purpose has been sooner and more effectually accomplished than it could have been had more costly works been attempted.
>
> "The most prominent features of American railroads involving a difference of principle in the plan of construction and management which marked them from their first introduction into this country are, first, the system of management of a public railway so as to constitute a complete work, *by means of a single track*, on all routes on which the amount of travel and business is insufficient for the support of a double track; and, secondly, the free adoption of steeper gradients than have been deemed admissible in England through all tracts of country where natural features do not admit of their reduction without an excessive cost. In the outset, as no such thing as a railroad with a single track for public use had been named in England, it was naturally imagined that double railroads would be essential to the success of any enterprise of the kind; but at an early period, a gentleman, then of this city, to whose mechanical genius the public are indebted for a number of important improvements, and who since that period for many years filled with distinction the office of Rumford Professor in Harvard University (we allude to Mr. Daniel Treadwell, now of Cambridge) first suggested the idea that a railroad for public accommodation might be constructed on a single track."

In the following article, which appeared in the Boston Courier of June 6, 1851, Mr. Treadwell bears equal testimony to his just appreciation of the value of the labors of his associate in the introduction of railroads into Massachusetts, and his own kindly personal relation.

TO THE EDITOR OF THE BOSTON COURIER: —

In the leading article of the Daily Advertiser of Wednesday last, upon the railways of Massachusetts, Mr. Hale has assigned to me a large share of credit for having first proposed, and for having advocated and defended, in various ways, the system of performing the whole business of a great public railway by a single set of tracks. As he probably thought that it would not be seemly for him, in such a place, to allude to his own labors, either in procuring the adoption of that particular improvement, or in the construction of the Massachusetts railways, generally, I beg permission to say that he was one of the first to perceive, not merely the economical advantages, which were sufficiently obvious, but the practicability, sufficiency, and safety of the railway constructed with a single set of tracks, and that he at once used his influence in its favor, which tended greatly to procure its adoption upon the Worcester and other early railways.

As a majority of the active men of the present day can have no personal knowledge of the exertions of Mr. Hale, twenty-five years ago, to impress upon the public the advantages to be derived from constructing railways in this country, I may be pardoned for asking a moment's attention to them.

Those who were readers of the Daily Advertiser at that period will remember his numerous and elaborate articles, furnishing all the information that could be collected, from foreign publications and letters, of the progress of railways in England, with estimates of their probable cost, their performance, and what might reasonably be expected from their construction here, in promoting the intercourse, and with it advancing the productive industry, the wealth and the power of the country. Of all the men who, by the labor of thought, writing, or speech, have contributed to the establishment of the railways of New England, Mr. Hale was, unquestionably, the earliest, the most constant, judicious, and efficient; and it must be pleasant to those who remember his old railway papers and reports to see, by his late articles upon the Hoosac Tunnel, that, as yet, "his eye is not dim, nor his natural force abated."

I trust that the public will not condemn me, as vain or presumptuous, for thus obtruding these few words upon its attention, especially as I do not give them as matter of authority or opinion, but as my testimony to that which has fallen under my observation; or as a relation of facts to which any man, however humble, if of fair character, may claim to be a competent witness.

DANIEL TREADWELL.

CAMBRIDGE, June 6, 1851.

In proof of the practicability of this improvement, it may be stated that in Massachusetts, in 1880, there were 1,893 miles of railroads, of which but 454 miles, less than one quarter, had double tracks. The Union Pacific Railway, 1,800 miles in length, extending from Council Bluffs to Cheyenne, had, in 1882, but 300 miles in sidings and double tracks, with gross earnings amounting to $24,000,000.

As to the safety of the two methods of conducting railway transportation, we have but few reliable statistics; one salient fact, however, appears with regard to collisions, — the accident that would be thought most likely to happen, — that out of 755 English accidents no less than 406, or 54 per cent, came under the head of collisions. In America, on the other hand, of the 3,763 accidents recorded, 1,324, or but 35 per cent, were due to collisions. With the telegraphic appliances introduced since Mr. Treadwell's time, the system of operating single track roads is nearly perfect, and the danger reduced to a minimum.*

---

* Notes on Railroad Accidents, by Charles Francis Adams, Jr., p. 266.

In 1828, Mr. Treadwell received a highly honorable appointment on the Board of Visitors at West Point, as appears from the following letters.

THE SECRETARY OF WAR TO MR. TREADWELL.

WAR DEPARTMENT, WASHINGTON, April 26, 1828.

Sir, — The regulations of this Department for the government of the Military Academy at West Point direct that the students of that institution be examined in all the branches of science and instruction through which they have passed, in the presence of a board of visitors, and such other literary gentlemen as shall be invited to attend; in conformity to which I have the honor to invite you to attend the examination of the cadets at West Point, which will commence on the first Monday in June next, as a member of said Board, and I shall be highly gratified to receive a report of your observations upon the actual state and progress of the institution, and such suggestions for its improvement as you may deem necessary.

Should you accept this invitation, Lieut.-Colonel Thayer, Superintendent of the Academy, will be instructed to make suitable arrangements for your accommodation.

I have the honor to be, sir, your obedient servant,
JAMES BARBOUR.

DANIEL TREADWELL, Esq., BOSTON.

HON. DANIEL WEBSTER TO MR. TREADWELL.

WASHINGTON, April 28, 1828.

Dear Sir, — I have much pleasure in forwarding to you the accompanying request from the Secretary of War. I hope you will find it convenient to comply with it.

Yours with true respect,
DAN'L WEBSTER.

DANIEL TREADWELL, ESQ., BOSTON.

MR. TREADWELL TO THE SECRETARY OF WAR.

BOSTON, May 6, 1828.

Sir, — Mr. Senator Webster has transmitted to me your letter of the 26th of April, inviting me to attend at the examination, in June next, of the students at West Point, as one of the Board of Visitors. I have sincerely to regret that my engagements will not permit me to perform the duties to which I am thus invited. I assure you, sir, that I am not unmindful of the honorable consideration which the invitation implies, and I beg you to accept my sincere acknowledgments for this mark of distinction.

With great respect, your obedient servant,
DANIEL TREADWELL.

MR. TREADWELL TO HON. DANIEL WEBSTER.

BOSTON, May 6, 1828.

Dear Sir, — I have received your letter of April 28th, covering a communication from the Secretary of War, inviting me to join the Board of Visitors at the next examination of the students at West Point.

I have been constrained by my engagements to decline the duties thus appointed to me, with a full acknowledgment of the distinction which the invitation to perform them confers.

Permit me, however, to express to you, sir, my sense of the increased value which this invitation derives from the high source in which it originated, and to assure you that amongst my most pleasant recollections will be that of having received from you this mark of consideration.

I am, sir, with sincere respect, your obedient servant,

DANIEL TREADWELL.

In 1829, Mr. Treadwell delivered a short course of lectures to the undergraduates and to the students of Harvard University generally, on subjects of engineering and practical mechanics, including the steam-engine and railways. As may be supposed, the last two subjects received full attention. The railway was in its infancy, and the desire was great to learn the method of its construction. The connection of the steam-engine with the railway, as a motive power, was not then thought of in this country; but the work that the stationary engine was doing in the coal districts of England was well known, as well as the success with which it was used on the steamboats of our rivers. The method of road-making was explained, and the force required to draw wagons over roads of different materials, in different conditions, illustrated with well-contrived apparatus, some of which was placed at the service of the government of the College by the Boston Mechanics' Institution, where it had been used by Mr. Treadwell in the several courses he had delivered there. The course before the undergraduates was repeated in 1830.

In 1829, he received from Harvard University the honorary degree of Master of Arts. His diploma describes him as "Virum Clarissimum Danielem Treadwell doctrina et artibus liberalibus omnibusque generosi animi affectibus imbutum."

Mr. Treadwell had now entered upon that period of his life when his inventive faculties were never more vigorous; he was thirty-eight years of age; he had studied carefully many of the operations in the trades performed by hand labor, and various machines of the useful arts, with a view to transfer the former to machines, or so to modify the latter that their products might be improved in quality at a diminished cost, which is the true measure of utility. Rope-making was then one of the operations performed almost exclusively by hand labor, or with machinery of the simplest kind, which had remained unchanged almost from the infancy of the art. He says, in the Autobiography: —

"It was this year, 1828, that I completed my first imperfect machine for spinning hemp for rope-making. This subject took up the greatest part of my time from 1828 to 1835, seven years, and comprised inventions that formed the subjects of five different operations, and included patents for preparing and spinning the hemp and tarring the yarn. These processes, which had been performed entirely by hand, were by my inventions transferred to automatic machines, with a vast saving in the cost of production and improvement in quality of manufacture." *

Machines, it might be added, on which a rope-yarn is spun by women's hands with almost as much facility as a cotton thread on a spinning-jenny.

The state of this art at the time of Mr. Treadwell's first invention is described in the following introduction to a paper contributed by him to the American Academy, and published in the Memoirs for 1833, entitled "A Description of a Machine called a Gypsey, for spinning Hemp and Flax."

"In all the methods of spinning cotton and wool, whether by the common wheel, or by more elaborate machinery, the material is subjected to a previous process of carding. The effect of this operation is to disengage the fibres from all entanglement with each other, and to leave them in a soft and uniform roll or roving. The spinning consists wholly in elongating these rolls or rovings, and binding the fibres together by a twist. Without the preparation by carding, or some preparation of like kind, it would be impossible to produce anything like the evenness requisite to the formation of good yarns, by any known means of spinning.

"The great length of the fibres of flax, and more particularly those of hemp, prevents the possibility of subjecting either of these materials to the process of carding, and the common method of preparing them for spinning is by passing them through the hatchel. Prepared in this way, however, they are incapable of being drawn out in threads like carded cotton or wool, but the interposition of the fingers is constantly required to supply the proper number of fibres, which the spinner takes from a mass, held about his waist or upon a distaff. I here speak of flax and hemp in their ordinary state, or having their fibres unbroken; in which state very little success has attended the numerous attempts to form them into threads by machines worked without the direct aid of human fingers.

"To spin flax or hemp by machines of that kind, it has hitherto been found necessary to subject them to a process which shortens their fibres to the length of a few inches, bringing them at the same time into a state in which they resemble a roving of cotton. They are then spun by machines not differing in any essential degree from the water spinning-frame or throstle. It has not been found practicable to apply this method to the spinning of hemp for cordage or lines of any kind; the cost of the dressing and preparation, not to mention the loss of strength produced by the breaking up of the fibres in forming the roving, being too great to bring it into successful competition with hand-work. It is, however, applied, to a considerable extent, for spinning flax, particularly for coarse cloths.

"It will be understood, from the preceding statement, that in the spinning of flax or hemp by machinery, as hitherto practised, one machine alone is used which is peculiar to that manufacture, the machine by which their fibres are shortened and formed into a roving. This machine consists of a cylinder about the periphery of which are placed numerous steel points. Near this cylinder is a pair of strong rollers. The cylinder and the rollers are geared, and, when in motion, the face of the rollers has six or eight times the velocity of the cylinder.

---

* On a pencil drawing is the following: "Drawing made October, 1828, by D. Treadwell, from which the first machine for spinning rope-yarns was built. This memorandum made Nov. 5, 1829. D. T."

The flax, being supplied to the cylinder, and passed between the rollers, is drawn through the points as through a hatchel. Several of these rovings are then just put together, and the process is repeated until the fibres are sufficiently reduced for spinning."

The first of the five operations of rope-making consists in drawing out the fibres of hemp into parallel lines, or splitting the fibres, if need be, and removing loose, short portions of the material, the *tow*, and any dust or foreign matter which would interfere with the subsequent processes. When this is done by hand, the workman takes a mass of the material by one of its ends and draws it through a number of long prongs of polished steel set in a block of wood called a *hackle*, repeating the movement until the fibres are parallel and clean; he then takes the mass of hemp by the other end, and does the same for the end which before he had grasped.

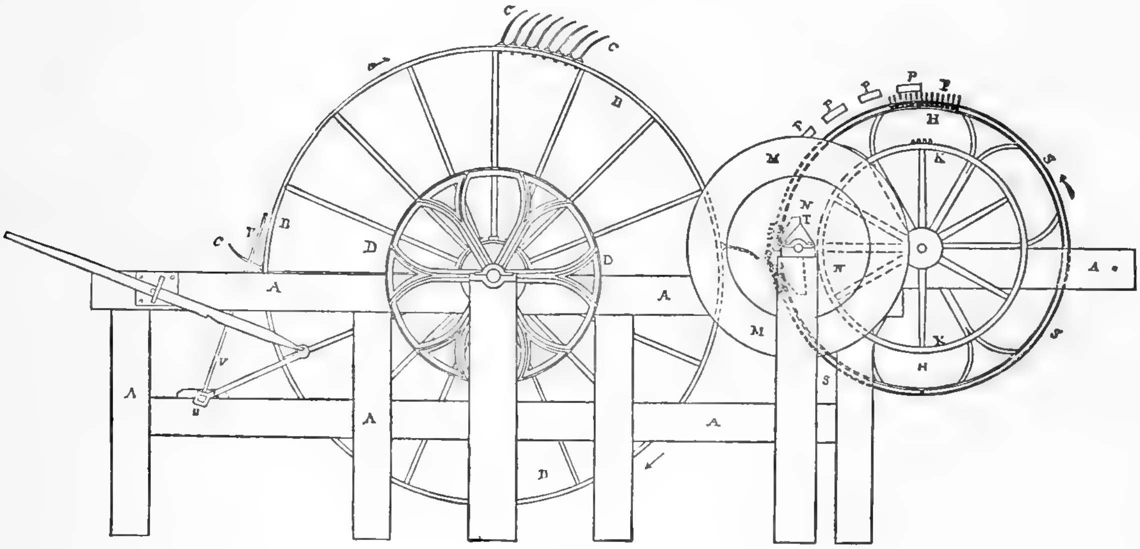


FIG. 1.

Mr. Treadwell's machine for performing the same work is described in his specification as "an improved machine for dressing, combing, or hatchelling hemp, flax, wool, and other fibrous substances."* It consists essentially of two cylinders of unequal diameter, set in a wooden frame, with their axles parallel. The great cylinder is completely covered with rows of steel points or teeth, C C, curved in the direction of its motion; its shaft runs in boxes on the frame, and is furnished with fixed and loose pulleys, M M, N N, E E, D D, Fig. 2. On the same frame is placed the small cylinder, covered with straight teeth smaller than those of the great cylinder.

---

* More commonly called "a circular hatchel or lapper."

The cogwheel K, Fig. 1, fixed to the small cylinder, is driven by the pinion L, Fig. 2. Over the small cylinder, just above the points of the teeth and parallel to the axis of the cylinder, are several *lags* or staves, P P. Alternating with every row of teeth is placed a rod or clearer, R R, Fig. 2; these rods are also parallel to the axis, and extend beyond the end of the cylinder, and are kept in place by two belts of leather, one at each end, to which they are secured by thongs. At each side of the frame is fixed a wedge or inclined plane, T T, Figs. 1 and 2, over which the ends of the rods or clearers must pass when the cylinder H revolves, and thus be brought near to the teeth of the great cylinder. On the opposite side of the cylinder B is a shaft having upon it a rack (P, Fig. 2, V, Fig. 3), one of the bars of which lies in one of the spaces between the rows of teeth of the great cylinder. To put the machine in operation it is only necessary to present the hemp, flax, wool, or other substance to be operated upon, to the small cylinder; the great cylinder being put in motion in the direction of the arrow, the small cylinder, with which it is connected by a proper belt, passes with the hemp upon it under the lags or staves, which press the hemp into the teeth. When the forward ends of the material thus carried in the teeth arrive at the point nearest the large cylinder, the wedges raise the ends of the rods or clearers, and with them the hemp out of the teeth of the small cylinder, so that it is struck by the teeth of the great cylinder, by which the operation of clearing, combing, or hatchelling is performed. When the hindermost ends of the hemp arrive at the wedges T T, the fibres slip from the

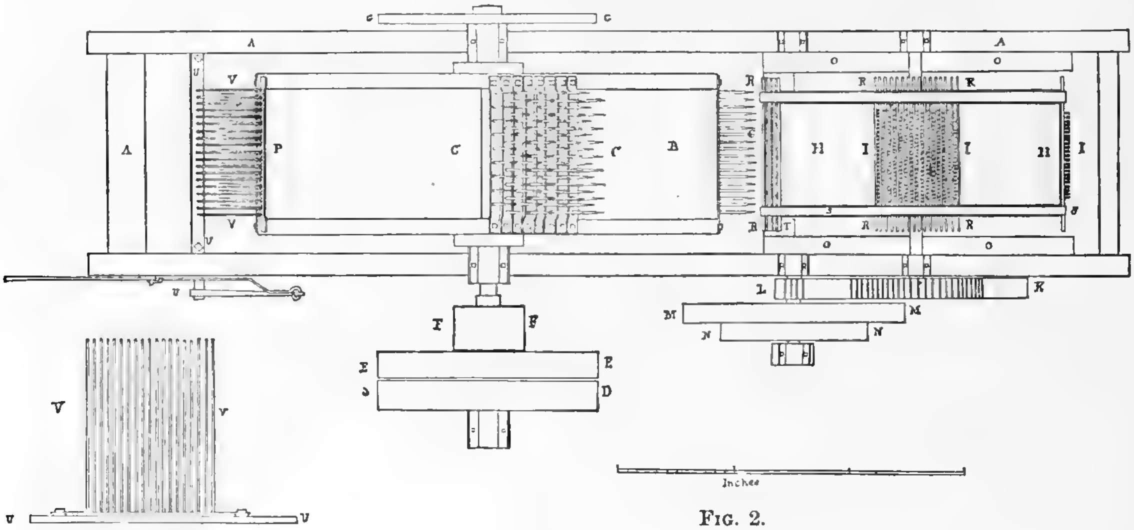


FIG. 2.

FIG. 3.

teeth of the small cylinder, and are transferred to the great cylinder, and revolve with it, being pressed down upon the cylinder by the action of the rack. When a sufficient quantity has accumulated on the cylinder to fill its teeth, the machine is stopped, the rack is thrown back, and the hemp taken off from the teeth of the large cylinder in a fleece. It may then be drawn into a roving. The patent for this machine is dated August 18, 1834.

The next process is the forming of a roping, roving, or *sliver* of a proper size, from the fleece of hemp prepared by the hatchel, as just described. This is effected by a machine called by Mr. Treadwell in his specification "a Belted Roving Machine," which is shown in Figure 1, on the next page.

B B are two cylinders, the axes of which run in the frame A A. E E is a hatchel belt. To form the belt several rows of points are fixed into plates of iron; the two outer points are formed into pins longer than the points, and upon the top there is a head. Other plates of iron, or clearers, longer than the first, and pierced with holes through which the points pass, are secured upon the outer pins, so that they can be moved freely up and down upon them. The plates bearing the points and pins are secured to a leather strap. This strap is supported upon a ledge on the inside of the rail F F, and movable upon it. The longer set of plates or clearers rests upon the upper edge of the rail F F, which is curved upward at the end on the right, next the head of the machine, so that the clearer as it advances is raised up to the head of the outer pins, and as it passes the pulley B remains in that position until it reaches, at the opposite end, the pulley B, when it is forced, or again falls down, upon the hatchel belt. Above this belt are the two pulleys I I, over which runs the bobbin-belt, H H, bearing wooden cylinders, or bobbins, alternating with the rows of points in the hatchel. J is a gear-wheel on the shaft of the cylinder B. K is a pinion driving the same. N is a pulley on a shaft, with proper gearing at its opposite end to drive the cog-wheel pinion K and the wheel J.

The head of the machine, at the right, is driven by the cog-wheel *p*, Fig. 2, which is geared with the wheel *o*, and drives the whole machine. *d*, *c*, *i*, *j*, *k*, and *f* are pulleys over which run two broad (ten-inch) endless bands, called drawing-belts or apron-belts. The pulley *f* is furnished with a sliding frame, *h*, and a screw and thumb-nut, *l*, for tightening the band. The endless band, *n*, moving in the direction of the arrows, passes over and encompasses successively the pulleys *d*, *i*, *k*, *j*, and none others. A similar belt, *m*, passes in the direction of the arrow over and encompasses the pulleys *c*, *f*, *d*, and none others. The band *m* is tightened by the

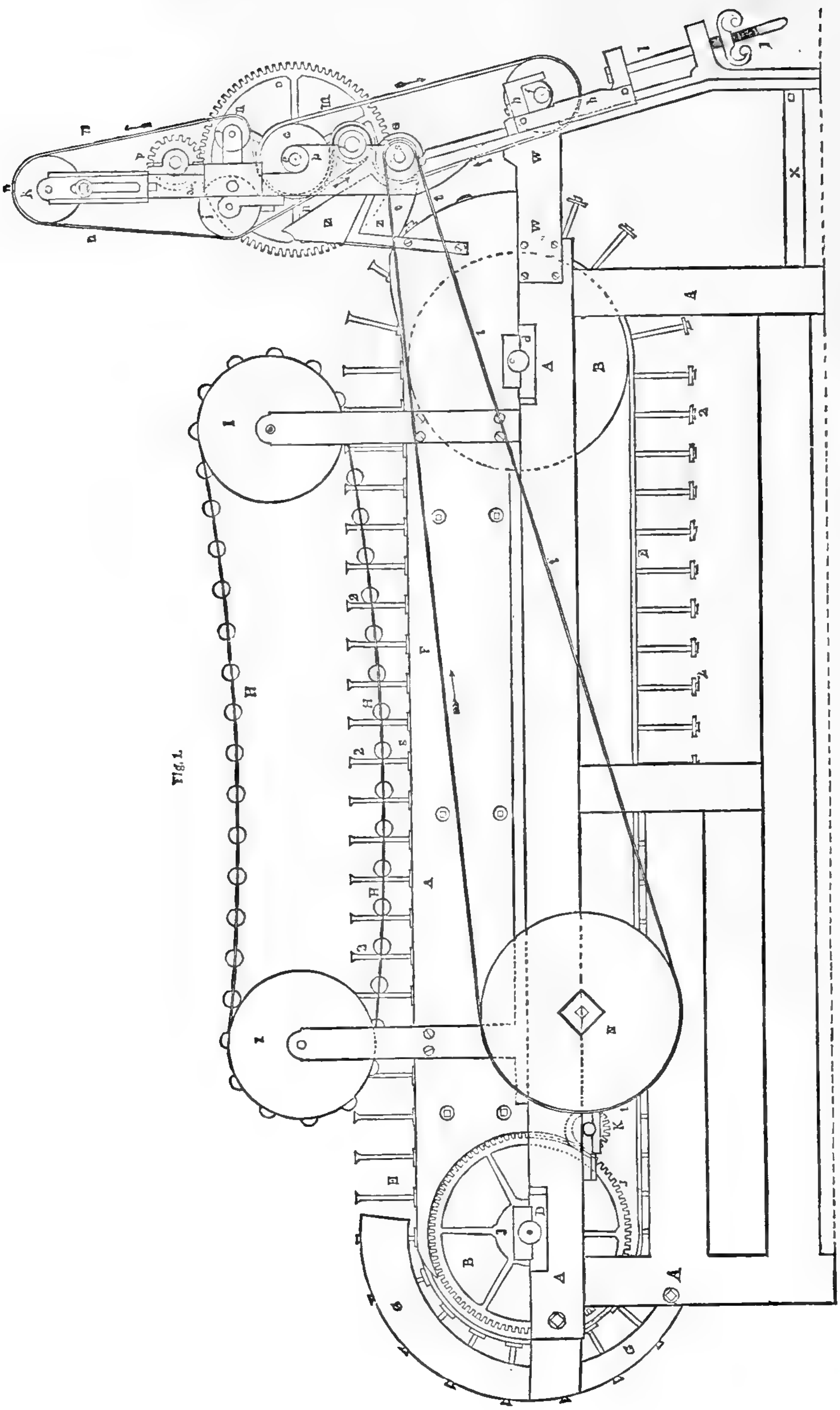
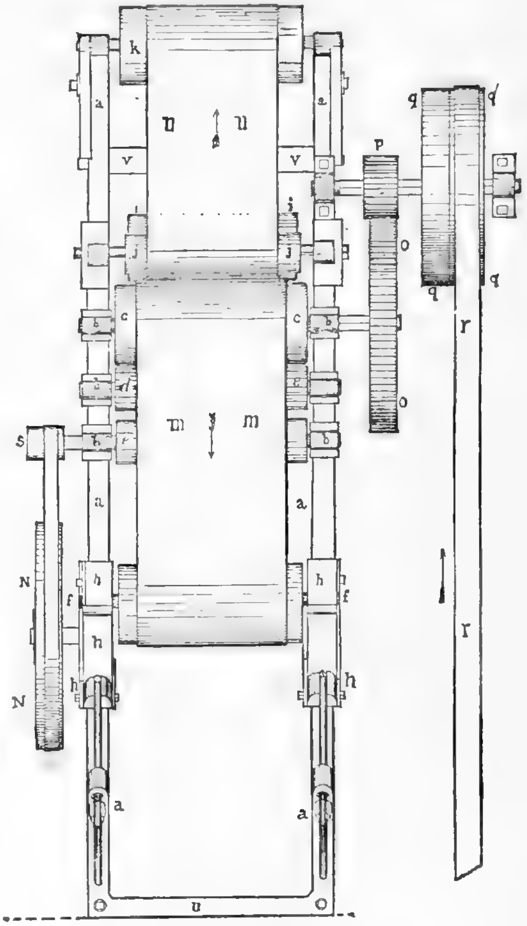


Fig. 1.

thumb-screw *l;* and the band *n*, by raising the shaft *a*, that bears the pulley K. *z* is a plate of sheet iron fastened to the frame, which, with another similar plate on the opposite side of the frame, directs the hemp to the drawing-belts *m* and *n*.

Fig. 2.

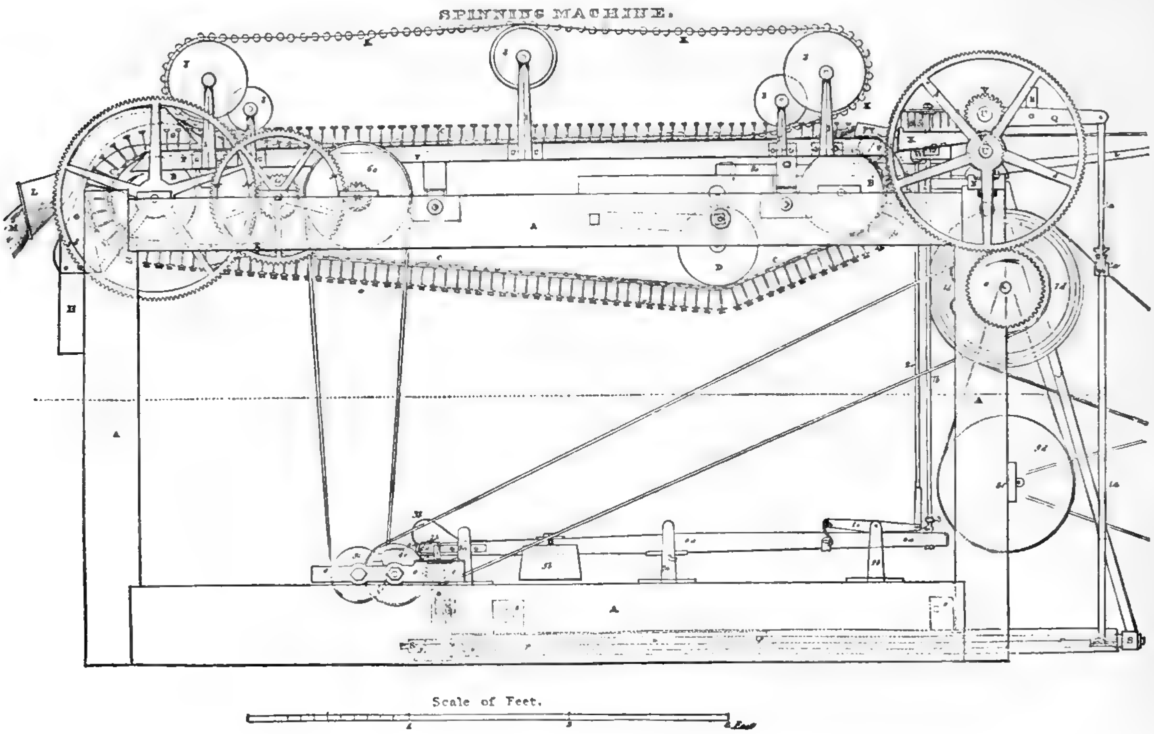


Now let us suppose the hatchel-belt E E to be moving in the direction of the arrow, and a portion of hemp forming a column or large roving to be placed upon a trough so that it shall be conducted to the points on the left of the hatchel belt, into which it will be pressed by the cylinders of the bobbin-belt, and pass along with that belt until it reaches the plates *z*. These plates direct it to the place where the belt *m* meets the belt *n* on the under side of the pulley *d*, Fig. 2, and around which these belts both pass. Now the tension of the belt *m*, being very great, this nips or presses the fibres of hemp very closely upon the belt *n*, passing round the pulley *e*, and they are carried in the space between the two belts, and on the outside of both, in the direction in which these belts pass, being drawn along wholly by the tension of the belts until the fibres reach the point between the pulleys *c* and *j*, at which the belts separate. The drawing-belts move much faster than the hatchel-belt, and the column of hemp which lies in the hatchel-belt must be drawn through the points, and be reduced in size to a degree corresponding to the greater velocity of the drawing-belts over that of the hatchel-belt. As the hemp may be continually supplied to the hatchel-belt, the fibres will continue to be formed into a roving, which may fall into a can as it is delivered from the belts, or, when drawn sufficiently fine, be twisted, by any proper apparatus, into a yarn.

The machine as now described was patented on the 5th of February, 1834. A more complicated machine for the same purpose, arranged for use with the spinning-machine, had already been patented on the 11th of October, 1831.

The hemp, having been formed into a roving by the machine just described, may now be passed into the spinning-machine, called a "Gypsey."

> "As it enters the machine, it lies on a hatchel similar to that already described, where every fibre is free to move in the direction of its length, without carrying any other fibres with it, whenever a proper force is applied for the purpose. The instruments by which this force is applied are a pair of rollers, which are moved with a constant velocity. Provision is made in the machine that, whenever the number of fibres between the rollers is too small to form a yarn of the required size, the hatchel containing the roving shall advance and present a new supply of fibres to the drawing rollers. This advance is made with a greater or less velocity, corresponding in some degree with the quantity of the supply required. When, by the supply thus given, the yarn has become of the required size, the hatchel ceases to advance, and further, if the supply has become too great, a small hatchel or comb is made to pass into the roving between the drawing-rollers and the hatchel-belt, and thus some of the fibres are broken off, and the advance of any loose fibres, that were drawn along by others in contact with them, is interrupted. When by this means the yarn has become of the proper size, the comb is made to rise from the roving, which may then be advanced as shall be required for the supply of the rollers."



The Gypsey.

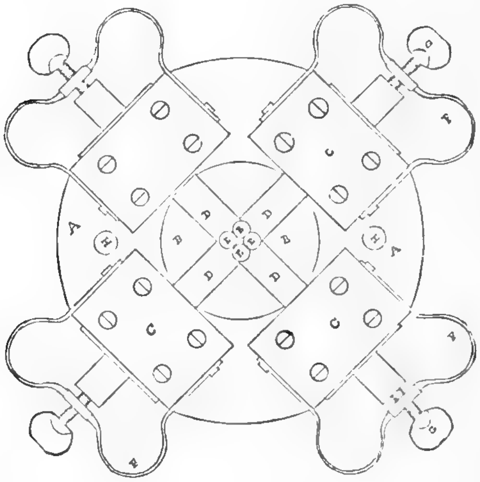
A full description of this machine, with the parts figured in detail, will be found in Appendix I.

To fit rope-yarns for certain kinds of cordage it is necessary that they should resist the action of water. They are for this purpose treated with tar. This had usually been done by a very simple apparatus; the yarns being drawn through an ordinary kettle of hot tar, the superabundant tar squeezed out, and the yarns wound on a reel. In 1834, Mr. Treadwell invented "an improvement which consists of three distinct parts: first, in the method of heating the tar; second, in rubbing and untwisting the yarn for the purpose of saturating it with tar; third, in the nippers for pressing out the superabundant tar." The bobbins, upon which is wound the white yarn, are arranged in any number at one of the ends of a long trough, which contains the tar, heated by steam-pipes. Above this trough is arranged a frame, having on its legs plates of iron pierced with holes, through which the rope-yarns pass. On each of these plates are two others, one on each side, also pierced with holes for the yarns; these plates are fastened to rods, which are attached by cranks at their upper end to a rotating bar, and also at their middle by means of pins to the frame. When the cranks are turned, the plates have a rotary motion around the holes in the middle plate, by which the yarn is untwisted and prepared to receive the tar; they then move on, the twist being taken out as they move, and pass between two rollers, the upper one movable and weighted, by which the superabundant tar is squeezed out and the yarns wound on a bobbin. Some of these troughs are thirty feet long, and the yarn from a hundred bobbins is drawn through the tar at one time by a capstan. They are still in use at the Charlestown Navy Yard.

The last operation in rope-making is the twisting and combining of the yarns into a large cord. It is necessary that the yarns should be laid side by side, and twisted together in a regular spiral. This is effected by a conical piece of wood called a *top;* it has equidistant grooves along its sides, into which the yarns are laid, and by which they are directed as they come together at the smaller end of the top. To hold back the top and increase the hardness of the rope, two or more cords or "tails" are attached to its sides, which the workman grasps, and, by winding them around the rope already made, regulates by their friction the hardness of the twist given it by the twisting-wheel. The success of the *lay,* its evenness and firmness, depend upon the judgment of the workman. For improving this process, Mr. Treadwell invented the instrument which he calls an "Iron-tail," the character of the invention being comprised in the construction and use of rubbers formed of some solid body, by which they are capable of preserving their own figure, and of constraining the rope over which they pass to assume the figure defined by them.

Combined with the top, it is intended to hold it back in a more equable manner than the rope-tails, and thereby give a more equable hardness to the rope.

The figure represents a tail to make a four-stranded rope. A A is a disk of wood or iron, having through it the hole or opening B B. C C are four blocks screwed upon the face of the disk A A. D D are four solid cylinders, or rubbers, which pass from the centre to the circumference of the disk, each having on its inner end a ridge to fit the crease between the strands. F F are springs, which, with the thumb-nuts G G, press the rubbers against the strands at E E. H H are holes in the disk, through which pass rods or ropes to keep the tail at a proper distance from the top. To use the instrument, the strands of which the rope is to be made are passed through the disk between the rubbers; if the *top* is then put in place, and secured at the right distance from the tail, which is so held that it cannot turn round with the rope, it will lay the strands even and smooth one upon another, without starting the tar.



In 1831, after Mr. Treadwell had observed the working of his machines for six months he declared, in answer to the inquiries of one of the Commissioners of the Navy, Commodore Charles Morris, that the same amount of cordage from the same material which by hand-spinning would cost $30 a ton could be made for $15.62 a ton. "After a full consideration of these subjects, I have concluded that I will furnish any number of Gypseys, from fifty to one hundred, with all the roving and preparing machines, at $1,000 for each Gypsey." It was also shown that the rope produced is of a better quality, and stronger, than that made from hand-spun yarns. Inasmuch as no spinning grounds will be required, the cost of buildings will be much less; and, again, the work can be carried on at all seasons, which is not possible with hand-spinning. The offer to furnish the machines for the Charlestown Navy Yard was accepted. In 1832, a factory was also established by Mr. Treadwell on the Mill-dam, in Boston, capable of manufacturing nearly 1,000 tons annually.

Previously to this, a joint stock company was formed, under the name of the Spinning Company, by Francis C. Gray, Horace Gray, and Daniel Treadwell. This continued until 1833, when another and larger company was organized, the Boston

Hemp Manufacturing Company, which carried on the work of making cordage until 1858, about thirty years.

During the whole period of the early manufacture of rope by this machinery, Mr. Treadwell had met with determined opposition from the trade of rope-makers, and was often insulted, and threatened with violence. After it was learned that an offer had been made to the Government to furnish machines, and that rope was in process of manufacture with them by the Government, the opposition took a different and more organized form. The rope-makers outside of the Government works were strenuous opponents of machinery, and had been zealous in promoting the designs of some rope-makers from New York and elsewhere in getting up a remonstrance to Congress against machine-spinning.* There were then eighty machines at work at the Charlestown Navy Yard.

In 1840, the Board of Navy Commissioners appointed Commander Joel Abbott, to examine the whole subject. A competitive trial was instituted. Four spinners from a neighboring ropewalk made an application to be allowed to spin and make a rope in their own walk for the purpose of entering into a competition of strength with the machine-made rope. Every facility was given them to prosecute their designs. They selected a lot of hemp from the Government ropewalk, which was divided into two equal parts, one to be spun by hand and the other by the machines. Two of their own number were present at the making of the rope by the machines. The spinners selected were of the best, and they were disposed to do their best: they expressed their most confident belief that they could spin by hand a stronger rope than could be made by machine-spun yarn. They spun carefully, and completed a rope of the very first quality. The trial of strength was made in the presence of four of their number. The result was, that the machine-spun rope sustained before it broke a weight of 1,469 pounds, while the hand-spun rope of the same size broke with a weight of 1,278 pounds. By other and careful experiments made at the same time, it was shown that the cost of spinning one ton of hemp by hand was $29.25, and by the machine $14.13; that is, half the cost of that by hand.

---

* A similar opposition to steam-spinning seems to have existed in England. The "London Mail" for February, 1866, has a speech of Lord C. Paget in Parliament, in which he says: "My honorable friend, the member for Rochester, found fault with me for adopting steam-spinning at our dockyards, and complained that it tended to take away the valuable occupation of hand-spinning. I am afraid my honorable friend will find fault with me still more this year, for we intend to extend our steam-spinning. We propose to introduce steam-spinning at Devonport, with the intention of abolishing the ropery at Portsmouth, and contenting ourselves with the two steam-spinning establishments at Chatham and Devonport."

> "It seems worthy of remark," says the Report, "that the machine-spun rope is always a *maximum*, owing to the perfect uniformity of the yarn, without the variation in size and twisting which is unavoidable in hand-spun yarn. The uniformity in the results of the many tests which have been made in this yarn abundantly prove this fact. But, on the other hand, the hand-spun yarn is not of uniform strength; for in the same rope the weight borne by the different pieces cut off for testing have proved greatly at variance with themselves; sometimes a piece will show great strength, and the next piece perhaps will fall greatly below it. The rope, therefore, cannot be depended upon for more than the *minimum* strength. This certainty on the one hand, and uncertainty on the other, is an advantage of inestimable value in the machine-spun rope." *

The report fully sustains Mr. Treadwell's statement to Commodore Morris. The machines soon came into use for the mercantile marine; a large manufacturer in New Bedford had one hundred and twenty in use at the same time. Besides spinning rope-yarns, the Gypsey was, in 1840, modified, and then came into general use in the Western States for the spinning of small yarn for the manufacture of various kinds of bagging for cotton and other coarse cloths.

From a report made some years since, it appears that the saving to the Government at the Charlestown (Massachusetts) Navy Yard alone was from ten to twenty thousand dollars annually, without mentioning the benefit derived from the superior quality of the cordage. On these machines and those copied from them and erected at Memphis, Tennessee, seven years later, all the cordage for the American Navy is spun, and they stand now without a successful competitor in the Navy Yard at Charlestown, as efficient as when first placed there fifty years ago. By their invention, the character of American cordage was so greatly improved that it became an article of export to most parts of the world, — to the British Provinces, the East Indies, and Great Britain. The machines also were exported first to Canada, and in 1860 to Great Britain, where they were soon adopted in the various dock-yards. Their use is now almost world-wide. One of the inventions, the circular hatchel or lapper, is believed to be generally used wherever hemp is spun for the making of coarse cloth.

The following letter from one of the largest manufacturers indicates the position that the Gypsey holds in their estimation.

TO DANIEL TREADWELL.

NEW BEDFORD, December 8, 1866.

My dear Sir, — On my return from Pennsylvania, I found your esteemed favor of the 19th ultimo. In reply, I would say that, while your invention undoubtedly lies at the bottom of all

---

* Report of Commander Joel Abbott, U. S. N., June 15, 1840.

self-operating machinery for spinning hemp, — is the basis upon which all others have been built,—yet in the course of the past we have found it necessary to alter and materially change their operation. While we do not and cannot get greater excellence from our present machines than from the former ones built under your directions, we get greater quantity with about equal quality, and that is a very important matter.

We are now running nearly one hundred machines, — about one half machines of our own construction, changed somewhat from yours. Twenty are machines built in New York, and some twenty-six are built after a pattern of Mr. Day's. The first and last are of about equal excellence, and the New York machines are very inferior. The greatest improvement has been made in the preparatory machines. In that department we have none of yours now running, we have machines somewhat similar, and more effective. They all, however, are but modifications of yours. It will give you pleasure to learn that our cordage has attained a high reputation, standing second to none in our markets, while it is quoted in San Francisco as of the highest rank. This is mainly owing to the greater twist and consequent firmness given to our yarns from the operation of the machine.

When I have a leisure hour, I shall with great pleasure call on you in Cambridge, where I now have a sister-in-law residing. I may say in closing, that neither my brother nor myself has ever had occasion to regret the hour when we made an arrangement with you for your machines.

Very truly and respectfully yours,

William J. Rotch.

Another of the large New England manufacturers reports that no successful rope-spinning machine is in operation (1886) that in its essentials is not based on Mr. Treadwell's. Some changes have been made which render the machines more productive without material injury to the quality. All kinds of hemp are spun on them. The number now in use must be much larger than ever before.

In perfection and utility, Treadwell's Gypsey ranks with Arkwright's spinning-frame; in ingenuity it far excels it; and they stand side by side in the character of their respective products.

In Professor Treadwell's inventions the material from the bale, after being by his preparatory machine cleared of all extraneous matter, without special regard to size or smoothness, enters the machine, and lies upon a belted hatchel, through which it is drawn by rollers having a constant velocity, each fibre free to be moved in the direction of its length without carrying others with it. By this means the fibres of hemp are straightened and laid parallel, so that they are best prepared for spinning, and for the finished yarn. If the number of fibres is too small to form a yarn of the required size, the hatchel containing the roving advances, and furnishes a larger supply of fibres to the rollers; when the roving is of proper size, the hatchel stops; if the supply is too large, a smaller hatchel combs out the surplus. Then passing to the spinning section, it is drawn, twisted, and wound upon a bobbin, a perfect yarn. The Gypsey is automatic; it asks nothing of the workman but to supply material, and to join the ends of a yarn if it happens to break; and even of this it takes care to notify him by instantly stopping, and does not again start till the yarn is made whole.

If Richard Arkwright merited knighthood and wealth, as he certainly did, for his combination of inventions already known, and their application to new processes, by which a new character is given to cotton manufacture, Daniel Treadwell deserves to be held in grateful remembrance for the originality of his inventions, the new combinations and new applications of others, and for the ardor and perseverance with which he overcame great obstacles and great opposition, and gave a new character to rope manufacture, at once enlarging its field, improving its quality, and diminishing its cost, — "which, in manufacturing," as he says, "is, other things being equal, the universal and only true measure of utility."

The profits from the spinning-machine from 1836 to 1838 were $15,166; for 1839, $12,359. Of this Mr. Treadwell had twenty-five per cent. In 1839, forty spinning-machines were made for the United States government; four preparing and roving machines, at $500 each; and a circular hatchel, at the same price. The profit on the forty machines at the Charlestown Navy Yard was $12,360. In 1844 the machines sold to a single company gave a profit of $15,385. Besides this, the sale of rights to use the machines was valuable. Mr. Treadwell received, as the manager of the manufactory, at first $1,200 a year, then $1,500, according to the profits; in 1832, his salary was $2,000, and probably so continued till the sale to the Hemp Company, at which time sixty machines were in operation.

At the end of Mr. Treadwell's account-book with the Spinning Company is the following, in his own hand: —

> "Spinning Company began in 1828 and ended in 1858, thirty years. An entire change in the manufacture of cordage produced by it. A great amount of labor, ingenuity, and mechanical knowledge exhibited by me in the five distinct inventions which I patented in connection with it. I have obtained but very little credit from these inventions, and by no means the profit in money that they deserved. Cambridge, Feb. 3, 1858. And thus I finish the account. Daniel Treadwell."

Again, in his Autobiography: —

> "It is dangerous for a man to judge of the merits of his own works, but I have always thought I have received from the public but a scant measure of credit for my inventions in spinning hemp. Few persons know that such means exist, fewer still that they are of my invention. I believe that, if a competent man were to compare these machines with many of

the more famous inventions, and understood the difficulties overcome, and the means devised for overcoming them, he would accord to these inventions a very high place among modern machines."

Mr. Treadwell did not escape the ordinary consequences of a successful invention; they testify to the value of the invention, but are of little direct use to the inventor: —

> "In a few years after the successful establishment of my spinning-machine, imitators and pirates sprung up in all directions. I never undertook the legal defence of my rights, preferring to suffer pecuniary loss rather than endure the delays and vexations of a suit, as the law of patents was then administered."

Seventy-six of Mr. Treadwell's machines are at this time (October, 1887) in use and in good condition in the Government ropery at the Charlestown Navy Yard, spinning day by day yarn that has never been excelled. The rope made by the Government for the Centennial Exhibition at Philadelphia, in 1876, was spun upon them, and was exhibited as the best rope then made. After more than half a century, by the perfection of their products they still bear testimony to the wonderful ingenuity and faithful workmanship of their inventor and maker.

The development of machine spinning may be inferred from the fact, that, in 1886, 125 millions of pounds of hemp, valued at about ten millions of dollars, were spun upon machines in the United States alone, valued as cordage at fifteen millions of dollars.

"In 1831," says the Autobiography, "being then in my fortieth year, I married Miss Adeline Lincoln, a daughter of Dr. Levi Lincoln of Hingham. She has been my faithful and devoted companion to the present time (1854), and I trust will be preserved to me to my end." *

This most happy union he communicated to his friend, Dr. Sweetser, in the following letter: —

To Dr. Samuel Sweetser.

Boston, October 14, 1831.

Dear Doctor, — Let me draw you a domestic scene. It is a gentleman sitting in his own well-furnished parlor before a comfortable fire, the evening being cool, his wife, good-humored and well pleased of course, beside him, now plying the needle, now casting a glance at the misty future, now dropping a word on the domestic economy or proposing some improvement in the household affairs, and then instancing the application of some fact of history or trait of

---

* Mrs. Treadwell was born on the 24th of May, 1804, and died, without issue, on the 28th of May, 1885.

character to bear upon the purpose of life. Is it not very well? More, is it not very excellent? And will you believe it, my dear Doctor, it is but a sketch of me, your old friend, and my *wife.* Yes, I am married. "Fast as the CHURCH can bind us, we are one." To leave this facetious vein, as Ware would say, I was married on the Thursday evening before the last, October 6th, and I should have written to you before to obtain your congratulations, if I had found myself sufficiently disengaged, even for so short and pleasant an act of friendship.

I am very happy, Doctor, in the prospect of the future, — every way satisfied with my choice. It is the more valuable to me, as I have arrived at a period of life when, having "supped full" of celibacy, a wife became necessary to me. I had fully proved in my particular practice a general truth which most persons will assent to, from the considerations of reason, — that, in the early period of life, a man devoted to some pursuit of science or art may support himself against external circumstances by the action of his enthusiasm; but a little later he requires the ties and relations which were provided in the laws of his being, and are necessary to the development of his capacities for happiness.

We have all desired to hear from you very much since you left us. All that we know of you is that you have received the Philadelphia appointment, Dr. P. having told Dr. Ware of it, and that you will, consequently, not be in Boston until late in the winter. We have missed you very much. P.'s relief has been in riding, which he has practised to the full of his poor horse's power, which, by the by, has not been wanting, as it has proved an excellent bargain, and will be the sum of two dollars in my fortune, as the insurance will expire before the horse does. Dr. Ware remains the same lively little philosopher; don't tell him that I have used the word "little" within a yard of his name, taking men's hearts by his good nature, money by his good practice, respect by his good sense, and, what pleases him more than all, applause by his good jokes, — sometimes by his bad ones. I pray you, Doctor, let me hear from you at your earliest. My wife joins me in the full assurance of our respects.

Very truly yours,

DANIEL TREADWELL.

In 1834, Mr. Treadwell was called to a new field of usefulness. He was chosen Rumford Professor at Cambridge, with the duty, as described in the will of Count Rumford, the founder of the Professorship, of teaching, "by regular courses of academical and public lectures accompanied with proper experiments, the utility of the physical and mathemathical sciences for the improvement of the useful arts, and for the extension of the industry, prosperity, happiness, and well-being of society." The title of the Professor, as established in the College Catalogue, was "Rumford Professor and Lecturer on the Application of the Sciences to the Useful Arts." He was now to assume the office of teaching the principles of mechanics and their practical applications, in addition to making new mechanical combinations as an inventor, which had heretofore principally occupied his thoughts. Those who knew him knew well that he would not enter upon such duties without forethought and preparation. The following letter defines his relation to the College, and his views as to the proper preparation required.

To HON. JOSIAH QUINCY, *President of Harvard University.*

BOSTON, January 10, 1835.

Sir, — Having had the honor of being chosen to the place of Rumford Professor at Cambridge, and being about to embark for England for the purpose of obtaining information on the present state of the arts, and for other purposes connected with the Professorship, I have thought that it would not be improper to state in writing the terms on which I understand myself to have accepted the Professorship, and on which I shall prepare to undertake the execution of its duties. First, the services required of me will be the delivery of about forty lectures annually on the philosophy of the arts, particularly those which are of practical importance in the business of life. These lectures shall be given, two or more a week, at such part of the academic year as the Corporation shall appoint. Second, to enable me to illustrate the lectures by direct experiments, the Corporation shall expend such sum as may be by them deemed necessary, which will probably be about five thousand dollars from the Rumford Fund in procuring an apparatus and collection of models of machinery. Such portion of the apparatus and models as can be advantageously procured in England shall be purchased there by me on account of the corporation. Third, my duties and salary shall commence on my return from England, and the first course of lectures shall be given as soon after my return as the apparatus can be completed. Fourth, the salary shall be eight hundred dollars a year, and the remainder of the yearly income of the foundation shall be expended in additions to the apparatus, the Corporation being at the expense of keeping the apparatus always in repair. Fifth, my residence shall be at Cambridge; but as the salary is fixed at a sum less than that given to Professors whose whole time is required in instruction, it is understood that I shall have leave of absence when not engaged in lecturing, for the purpose of attending to engineering, or any branch of industry the pursuit of which will enable me to render my lectures more immediately practical and instructive. I do not state the above as absolute conditions, intended to bind the Corporation in a literal fulfilment of them, but as a summary of my duties, and of the terms on which they are to be performed.

Very respectfully, your obedient servant,

DANIEL TREADWELL.

He sailed on the 2d of March, 1835, from New York for England, landed at Dartmouth on the 23d of the same month, and went immediately to London. Although he devoted himself with his usual energy to the visiting of such institutions as had for their object the advancement of the useful arts, and to studying carefully such practical operations in manufactures as would illustrate the subjects connected with his new duties, his letters to his friends at home show that he was an observer of the people and the effect of their institutions. The following letters and extracts from his Journal give us his impressions on this visit.

To DR. JOHN WARE.

LONDON, April 1, 1835.

My dear Doctor, — You will have learned by my letter to Adeline the course of things with me during my voyage and journey to this immense depot of the best and worst, the richest and poorest, of all that God has made. I find I had lost my realization of London by living in the village of Boston, and had again to go over my former astonishment at its interminable size and innumerable population. Perhaps nothing is more calculated to give a man a just idea of the insignificance of his own or any other individual existence, than a sight of the throngs of London. It is perhaps more than anything else calculated to check ambition, to see the unremitted struggle one is obliged to make under the most favorable circumstances to obtain reputation or wealth, and to estimate at the same time the chance of failure and the value of success even if attained. A lawyer, for example, with the best talents, commences practice, and after a life of labor, with good fortune, gets upon the bench in his age; in a few years, he is worn out and dies, or retires and is forgotten. Is the success worth the effort? Perhaps it is, but the labor is more, and the value of it less, than at first sight we think them to be. You may say that reputation is never an object worth striving for, — and I *fully agree with you;* but it forms, notwithstanding our opinion, the great motive with such men as Sir R. Peel, Mr. Baring, and others, for sacrificing what you and I should call our comfort and life. I went yesterday into the House of Lords, which was engaged in hearing appeals from the Court of Chancery. There were present the Lords Lyndhurst, Brougham, and the Bishop of Chichester. Lyndhurst appears much older than his years, but Brougham has all the activity and sprightly appearance of a man of fifty. His face is not wrinkled, his eye is bright, and his frame firm. He sat with his hat on, reading the documents of the case through his glasses, held before his eyes by his hand, as though he would balk the use of spectacles. He was active in going into the merits of the case, in hearing and putting questions to the counsel, Dr. Lushington, and seemed to take a more decided part in the trial as a judge than was taken by the Lord Chancellor. The Bishop of Chichester said and did nothing. Brougham is deserted by all parties, as much as his great predecessor Bacon was; and if the present ministry goes out, no one thinks Brougham will have any place in the new administration. . . .

Last night, April 3d, I attended a meeting of the Royal Society. Mr. Lubbock, V. P., was in the chair; Dr. Roget and Mr. Children, secretaries. The business of the meeting was conducted with great formality, the mace lying on the table before the V. P. As many as fifteen persons were admitted as Fellows, amongst others Mr. Featherstonehaugh of New York, whose recommendation was signed by Buckland and eight or ten others; but Mr. F. is an Englishman by birth and connections, and that accounts for his having been so brought before the Royal Society as to have been chosen, while men amongst us of more merit are not known to the men of science here. After the meeting, the members went into the library and took tea and coffee, and remained together an hour or so in familiar talk. . . .

I have spent several hours at Babbage's looking at his machine.* It is exceedingly ingenious as a mechanical invention, but perhaps more striking considered with regard to the evidence it furnishes of Babbage's knowledge of the theory of numbers.

I am more pleased with Faraday than with any one else I have yet seen in England. He is in his person not larger than a certain good friend of mine [Dr. Ware], and his face quite inexpressive, his forehead not large, and, in short, with nothing in his physical structure to attract attention; but his manners are so frank and cordial, such activity of mind and readiness to go right to the point, free from all affectation and humbugging, that I felt at home after three minutes' talk. . . .

---

* The calculating engine, constructed at the expense of the English government.

To Mrs. Treadwell.

London, April 10, 1835.

. . . You perceive that I am yet in this every way wonderful city. I remember heretofore having spoken slightingly of the practice of describing the country through which one passes on a journey, "of babbling of green fields," and therefore I shall not babble of smoky houses; but I cannot forbear the remark, that after one has passed for miles and miles through the streets of London, and seen ranges of buildings covered in many places (even some of the most obscure) with elaborate ornaments of architecture, and marked the ships, the docks, the bridges, and all the merchandise collected in warehouses or moving from place to place, he cannot but wonder, when he considers how little a single man can produce, that men enough have ever existed to have produced so much. It may be taken as a fair estimate, that to construct the docks alone it required a labor equal at least to that of a thousand men working a hundred years. This includes the warehouses and buildings belonging to the dock companies.

I am constantly on the alert to see and hear all that may be found, and I receive many facilities from those to whom I have become known; amongst others, I cannot express too strongly my obligations to Mr. William Vaughan, an old gentleman of eighty, the brother of Mr. Vaughan of Hallowell, and Mr. Petty Vaughan, his nephew, to whom I had a letter from Dr. Bigelow. Mr. William Vaughan is constantly casting round to see what he can do for me, and being a member of all the prominent societies, amongst others of the Royal Society, he is able to show me a great many men and things. I have heard lectures at the Royal Institution from Dr. Richie, Mr. Brande, and Dr. Lardner, all of which were *excellent*. Dr. Richie's was upon electricity. The experiments were not numerous, but all to the purpose, either as illustrating some theory or as displaying some fact which it was necessary to explain or connect with some theory. Mr. Brande's was upon the laws of animal and vegetable chemistry, of which he gave a general, but very clear and philosophical view. He is not popular, being considered past his time, and being entirely outdone by Faraday, who is said to be the best lecturer in London. I spoke in my letter to Dr. Ware of his manner and appearance. Since then I have met him again at the Royal Institution, and was further confirmed in my high idea of his powers. He is quick in his conceptions, and at the same time clear, deep, and accurate, and all his rapidity is calm and without *flutter*. Dr. Lardner lectured on Halley's comet, the approach of which to the earth is exciting considerable attention here. The philosophers are anxious to see the calculations verified by it, and it is said the *canaille* are anxious, as they expect it will bring some terrible disease or calamity. Lardner's lecture was a perspicuous account of comets and their laws of motion. It was learned, and at the same time simple, — "deep, though clear." You see by this I *am* capable of being excited to praise; indeed, these men come up to my notions of what lecturing should be; but then they are the *crack* lecturers of all London.

To Dr. John Ware.

April 22, 1835.

. . . In my last letter to you I promised to write particularly of Babbage's calculating machine. I thought that, on seeing it again, I might undertake to give you an idea of it, but I find that it would be impossible, as I have not seen it long enough to gain a thorough and clear knowledge of it myself. It is thirteen years since Mr. Babbage commenced making the drawings for it, and the calculating part of the machine now built does not extend to more than one quarter of the places of figures that he intended it to do, that is, it has but one quarter of its work in, and instead of counting, say 1,000, it counts but 250, but it works right as far as it goes. Nothing, or almost nothing, has yet been done to the part that is to stamp the figures on the copper. Drawings of it have been made, and a few of the pieces cast, and that is all. The stamping of the figures will require, as Babbage represents it, an apparatus as complicated as that for making the calculations, and what is more, an apparatus that must do actual *labor*, and, moreover, be actuated through the intervention of the delicate calculating apparatus. These difficulties are not, in my opinion, likely to be overcome, and would not be, even if Babbage were fresh in the harness, and the money were at his disposal; but this is not the case. Babbage indeed does not tire, (for he has lately commenced the drawings of a machine of greater powers than that partly made,) but the government have stopped the supplies, and the men on whose opinions the money was before given "begin to doubt," so that there is no chance of the work being taken up at present; in a word, the wonder of the machine has passed, and it is considered as laid upon the shelf. Mr. Peter Barlow, the Woolwich Professor, with whom I dined the other day, spoke of the whole quite slightingly. "Its powers," said he, "if it were done, would be very confined as a calculator; money enough has been spent upon it, and it is time that it was given up as an impracticable scheme." My own opinion coincides with Barlow's, but I honor Babbage for his ingenuity, as I consider the machine one of the greatest pieces of intricate conception ever put into form. . . .

In my letter to Adeline, I have said something of the lectures of Drs. Lardner and Richie and of Mr. Brande, and of the reputation of Faraday. Is it not a little strange that men so clear and excellent as writers and lecturers should be so unsound in practical things? I am led to this observation from learning their opinions on several practical subjects, one of which, a plan for a railway, which is as absurd as can well be imagined, (and you would see it is so at once, if I had room to describe it to you,) has obtained opinions from Faraday and Lardner recommending it in the highest terms compatible with any semblance of discretion. It would seem that there is a gulf between men of practice and men of books, or that books and household experiments do not teach or lead to practical wisdom. My hundred times told opinion you know, but here given with new instances. I ought, perhaps, to except two persons (you and I) from the common lot of other men, for we contrive to straddle the gulf.

Truly yours,

DANIEL TREADWELL.

EXTRACTS FROM MR. TREADWELL'S JOURNAL.

LONDON, May 15, 1835.

Went to the Royal Institution to hear a lecture on gunpowder, but the gentleman who had engaged to give the lecture having been taken ill, Mr. Faraday undertook to supply his place, taking, however, another subject for his lecture. Mr. Faraday had notice of this at two o'clock. He commenced by stating the circumstance as above, and said he had chosen the late discoveries of Savart in sound and on the ear for his evening's observations; that he had been led to this by a law of the mind, that was perhaps peculiar to him, that of feeling most confidence in his powers in subjects with which he was least acquainted.

Great approbation was shown of the lecture. It seemed impossible to me that it should have been prepared after two o'clock, the time when he said he received the note communicating the indisposition of the person who was to have lectured. . . . Mr. Faraday speaks in a low, soft voice, with an earnest and insinuating manner, is very quick in his delivery, and in his experiments apparently desirous of doing as much as possible in his hour. He is very dexterous in his operations, and does not seem satisfied unless his experiments succeed perfectly and strikingly. He sometimes uses words too strong for the subject, as by calling things "very wonderful" which are only a little wonderful; but here the fault seems to be a misconception of the thing, (if I may say so,) or perhaps a desire to magnify for rhetorical effect.

At the close of his lecture, Mr. Faraday alluded to the expected discovery of the new principle "which shall embrace all the laws of the actions and dispositions of bodies, as gravitation, electricity, heat, etc.," and said he believed that they would be found to be one, and to consist of some kind of vibration: but he did not show that he had any very clear notions on the subject.

Saturday, May 16, 1835.

Went again to the Royal Institution to hear Mr. Faraday's lecture in his regular course of chemistry to the members of the Institution. The room was well filled, many ladies being present, sitting with the gentlemen, which was not the case yesterday. The subject of the lecture was *Lead*. . . . Mr. Faraday then said that lead was highly inflammable, and burned it, first, by the electrical machine, secondly, by a stream of oxygen on charcoal, and thirdly, he had some granulated lead obtained by chemical means, that he said he believed was reduced to its primitive atoms. This was sealed up in glass tubes, and on breaking the tubes and letting the lead out, it inflamed spontaneously. . . .

The lecture was good and much liked by the audience. He showed all the peculiarities before noticed. Great fluency, readiness with the hand, simple and clear explanations, and a strong desire to give information. There were so many ladies crowding round him at the close of the lecture, that, after waiting half an hour, and seeing no chance of their leaving, I came away without passing a word with him.

MANCHESTER, June 9, 1835.

. . . I brought from Boston a diploma of the American Academy to Dr. Dalton,* the chemist of this place, and I this morning set about finding him. I had found in one directory that he was in 40 George Street, within two hundred yards of my hotel; but in another his name did not appear, and on the whole the search for him was the reading a serious lesson on *reputation.* I inquired of the innkeeper, who told me I should find Dr. Dalton in George Street. I then asked at the coach-stand close in the vicinity, where half a dozen hackmen were standing together. They repeated the name and looked ruminatingly upon it, but gave it up, never having heard it before. Next I went to a druggist's shop; no one here knew where he lived, although they had heard of such a person. Then to another druggist, who told me he lived in Faulkner Street. I went there, and at last hit upon the house where he lodged, but he was at his rooms in George Street, and to his rooms I went. I found a moderately sized brick house, like a public office or school-house, without any mark to designate to what purpose it was assigned, and without bell or knocker. I went in, and knocking at an inner door, a head, which I at once recognized from his bust to be Dr. Dalton's, was presented from a door opposite. I inquired for Dr. Dalton, and was told, "I am he"; on which I said I had charge of a communication for him, and I was desired to walk in. The room had several forms, and on

---

* John Dalton, the celebrated physicist, and founder of the atomic theory of chemistry.

the shelves a few phials and a small show of chemicals, and one boy about twelve seated and at his book. Immediately on entering and giving to Dr. Dalton his sealed packet containing his paper, I said this is from Boston. "Boston, and where is that?" On which I told him in America, and that the paper I gave him was a diploma from the American Academy. He then said that he had read the volume of Transactions, and liked it very well, particularly the paper on Meteorology, but that he wished the times of the appearance of the Aurora Borealis had been stated. He made several inquiries about the Academy, and desired to know when I should leave town; on my telling him, To-morrow, but that I should return after seeing Scotland, he said he should be very happy to see me on my return, and to furnish me with the Manchester Memoirs for the Academy's library, and with any or all of his papers and works, and desired likewise that I would call and take tea with him. Dr. Dalton I should think about seventy years old, of middling size, a little stooping, sharp-featured, and rather sprightly in his gait. He appears to be very near-sighted, and has the peculiar habit of drawing together his eyelids, which is common to near-sighted people.

London, April 10, 1835.

. . . Went with Mr. Babbage to the Royal Institution to hear a lecture from Dr. Lardner, who lectured without a note of his subject. He spoke rapidly, in choice, but familiar language, with a little of the Scotch or perhaps the North Country accent, aiming at pleasantry, but his lecture was excellent, well ordered, well proportioned, and very clear in the explanations. After the lecture Mr. Babbage introduced me to him. I told him I should like to see the apparatus of the London University. "Why," said he, "I have some there, but Dr. Richie, who has the place, will show it to you with pleasure." I told him that we saw all of his books in America, and that some of them were republished. He commenced a reply, as I understood him, "Yes, they are republished to my curse," — meaning perhaps the taking away his profit; but at the instant Faraday came up and asked us down to the lower library to take a cup of tea, which prevented Lardner from concluding his story. In the course of the evening Brunel* said to Faraday, "Mr. Treadwell brought me over a diploma of membership of the American Academy." I said, "Of which Mr. Faraday is already a member." Mr. Faraday said, "Yes, and I am quite proud of all such honors, and always put them to my name, because they are given without interest or favoritism." I said, "Yes, it may be said they are like the judgment of posterity." Babbage was very pleasant and attentive during the whole evening.

To Mrs. Treadwell.

London, May 17, 1835.

Dear Adda, — I have, as you know from Dr. Ware's letters, been in Wales since I wrote you, and you know the course of my journey. I undertook it for the double purpose of seeing the country, or rather the mining and making iron, and to procure a man for working the iron mines in Pennsylvania owned by Colonel Perkins, Mr. Jackson, and others. In this object I have succeeded, and have made an agreement with an experienced iron-master to transport himself to America to set up furnaces on the Susquehanna. At Bristol I went over the famous Redcliffe Church, where Chatterton pretended to have found the manuscripts of Rowley which he wrote. The edifice is a noble old pile, and I lingered about it for hours, absorbed with reflections on the remains of labor performed before a civilized foot had pressed

---

* The engineer of the Thames Tunnel, who began his career in the State of New York.

the earth in our whole continent. You know the story of the English lord saying that "the rich citizen might build a palace, but, damn him, he could not build the old trees." They may say of us, that we cannot make the old churches. The truth is, there is no town in England of any antiquity that has not churches that Boston has nothing to compare with. I do not know that Bristol, for example, is remarkable for churches, and yet it has more fine buildings of that kind than can be found in the United States.

I went to De Ville's a few days ago to see his collection of casts of heads, of which he has between two and three thousand. He is in the practice of examining heads to tell the characters of those who wear them for a fee, and I even put mine under his hands. He wrote out a character and gave the relative size of the organs. This he does by numbers going from one to seven. He gave me no number lower than two, and what of all the organs in my head do you suppose is so puny and behind-hand? Nothing else than *self-esteem*, or in other words vanity. I think the better of phrenology for this hit. Indeed, I always knew that I had not a sufficiently high opinion of myself. Tell the Doctor that his organ of self-esteem will probably be found not more than one in Mr. De Ville's scale, whatever may be said of it at home.

May 19.—I have just returned from Woolwich, where I have spent a very pleasant day with Professor Barlow, of the Royal Military Academy. I went down to the repetition of some experiments he has been making on the strength of iron. I met at his house, where I dined, two or three other engineers. On my return, found your letter of April 16th. I am obliged to you for looking to see how things go on at the Mill-dam, although I do not believe you will be able to know much about it. Yet I like to hear of it, for at the sight of the name of the Gypsey I can hear the humming of the wheels. England is in a very prosperous condition at this moment, with the exception of the agricultural interests. The manufactures of every kind are in good employment, and I am told several large cotton-mills are building at Manchester.

Societies are as much in operation here for charitable and moral purposes as they are in America, and I have no doubt but they produce good results. I am certain that there is less vice in London now than there was when I was here fifteen years ago. Begging is rare, and the practice of crime in the streets is by no means so common as formerly. This is to be attributed partly to societies, partly to the improvement in the police, and more than either of these, perhaps, to the cessation of war and the partial relief of the lower orders from its burdens. Whatever the cause, the morals of the people have improved in everything except the practice of temperance.

Ever faithfully yours,

DANIEL TREADWELL.

TO DR. JOHN WARE.

MANCHESTER, June 2, 1835.

My dear Doctor,—I think you will agree with me that the most pleasant letters are those which concern some of the prominent men amongst whom the writer may be placed, or of whom he may be in a condition to collect incidents. If the relations are of a scandalous character, or tend to bring the mighty down to our own level, the interest is exceedingly increased. Letters relating to the mere people, those atoms of mortality of which the substance called mankind is formed, excite few sympathies, unless we can fix upon some great atom called a leader; and yet of how much more importance are the people than the leaders, of whom we think so much! The sum of happiness or misery, for example, that comforts or afflicts the mass of common people, how much more is it in amount than that which belongs to the high and refined! Not that any individual of them can feel so much, but that their number so far exceeds the number of the higher order.

Since I was in England in 1820, a wonderful change has taken place in the political opinions of the men in trade and the master manufacturers, and indeed of those of a somewhat higher order. They now entertain all sorts of radical notions. They seem to have forgotten their ancient love and reverence for most of the old institutions, and although you will hardly find a man who does not hold the King in honor, nothing is more common than to hear them rail at the Lords and the Church, and hope the time is coming when they shall be rid of both. This giving up of old opinions, which were of a definite character, and held men to one mind, has had the effect of producing all sorts of strange doctrines in politics, as every man now *invents* his own opinions; consequently they are as various as the faces they go with, and agree only in one point, namely, opposition to the Tories, and reforming the state.

In religion, the people are sincere, and are, I think, as much attached to it as they are in New England. I have hardly seen a Sabbath more strictly kept in Boston than it is kept in Birmingham. The Methodists are of immense importance to social order, in taking up and *religionizing* the lower classes. My opinion is that the Methodists do more good than all the other sects together in England, as they take the class that could not be managed by the law without the aid of religion, whereas the higher orders could perhaps be governed and *get along* without it. There is considerable infidelity amongst the radicals, but not amongst the lowest of them, so far as I have seen.

We have in the United States a very wrong opinion of the condition of the operatives in the manufacturing towns. I have had this constantly in mind when amongst the coal and iron workers in Wales, the doers of all work in Birmingham, and now among the spinners and weavers of Manchester, and I have seen everywhere the people well fed and well clothed, and if their habits were improved, if they would learn to save their money, absolute poverty would be unknown or rare. I do not, by any means, intend to say that the people are as well conditioned in England as they are in the United States, but that their condition is better than we in the United States have supposed it to be, and that with the operatives it has generally improved within the last fifteen years.

I ought to have mentioned that the slavery in the United States is very offensive to the radical politicians; that they insist on its abolition, and that I have often given great offence in stating the difficulties which lay in the way of giving freedom to the slaves. They are as savage for freeing the blacks as our Southerners are for non-intervention, and will not hear a word of its being no concern of the Eastern people. They suppose that there is no limit to the powers of the general government, and that Congress has full right to bind the States to all purposes. Probably not one half of the members of Parliament even have ever read the United States Constitution, and the common people know nothing about it.

I begin to tire of this chasing from place to place, and nothing but the excitement of learning something new, or fixing as certain what before was conjecture, would make it tolerable.

Yours truly,

DANIEL TREADWELL.

To Mrs. Treadwell.

Glasgow, June 20, 1835.

Dear Adda, . . . Last Thursday I went to Abbotsford in company with Colonel Benjamin Loring, whom I met with by chance on Sunday last at York. The house and furniture are all in the exact state in which they were left at the death of Sir Walter, and are shown to visitors by an intelligent woman, who was long in the service of the family, and who, with her husband, are now the only inhabitants of the place. She told me that the loss sustained by Sir Walter from Constable's failure was a death-blow to Lady Scott, whose lofty spirit was broken by it; and she survived but about a year, and died in 1827. . . . It was while on his journey, and near Naples, in 1832, that the last and terrible shock came upon Sir Walter, from which he never recovered the use of his speech or reason. He never, except in one instance, appeared to know any of his former friends, or any one of his family. This instance, in which he gave signs of a glimpse of rational power, was on his arrival at Abbotsford, in June, 1832, where, on meeting Mr. Laidlaw at the door, he said, "Now, Laidlaw, I know that I am at Abbotsford, for I see you." From that time, however, he gave no signs of memory or reason, was incapable of feeding himself or doing the least office for his personal comfort, but passed his time in making a constant loud and piteous moaning, or roaring, which might be heard to a considerable distance from the house. In this condition he continued from June until September, when he was released. Such is the story of the housekeeper, and I have no doubt that it is true. I have never seen it in print, and, melancholy as it is, I thought I would send it to you.

There is in this travelling a great deal that is uncomfortable, for one can come at that which he wishes to see and know only by looking it out amongst a vast number of things he cares nothing about. This is particularly the case with me, as I am not looking after fine scenery and other like objects of the pleasure tourist, but for every-day arts, which are not subjects of show. I keep constantly at work, however, and some way or other generally find what I want to see. I shall be glad when it is over, and I can say I have seen all that I came to see.

Ever yours,

Daniel Treadwell.

To Mrs. Treadwell.

London, July 6, 1835.

My dear Adda,—You will perceive by the head of this letter that I have returned to the City of Cities once more. My return from Glasgow was through Liverpool, Stratford upon Avon, Warwick, and Coventry, to London. I have had every reason to be pleased with my journey to the North, particularly with the Scotch part of it, and shall remember to my dying day the remarkable appearance of the Scotch scenery in the Highlands, the strange mixture of good taste and magnificence with the barbarism and filth of their cities, and the combination of high intellect with naked feet in their inhabitants. This last is a striking *feature* in Scotland, as I do not think I saw ten pairs of shoes and stockings for the many thousand female feet in the factories of Glasgow. The males were modest enough to wear shoes, but the females of the class who do work of any kind, which may be taken at three fourths of the *sex* in Scotland, so far as I saw it, go barefooted, and that out of doors and in wet weather, as well as in the house.

I was much more pleased with the master manufacturers of Glasgow than with those of Manchester. I found them possessed of more knowledge of the science of their arts, with a greater disposition to free communication of their methods of practice. I saw but few of their scientific men, as I was there at the time of the College vacation and the Professors were mostly absent. Dr. Hooker treated me with great politeness, and gave me access to the College buildings, library, and Hunterian Museum, and insisted on introducing me to Dr. Thomson, but unfortunately we found him *awa'*.

At Stratford upon Avon I was well repaid for the hours that I passed there in visiting the house in which Shakespeare was born, and the stone beneath which his dust now remains,— the beginning and the end. In viewing the scenes about the town, and identifying them with Shakespeare in his youth, the predominant feeling was that of wonder that an individual surrounded with these commonplace things of life, and brought in daily contact with common men, eating and drinking with them and taking part in their petty affairs, should at the same time have possessed that power which in after life developed itself in acquiring and displaying that perfect knowledge of the characters and passions of men in all the varieties of kind and condition which stamps his immortal works, and passed from the stage when, with a small property, he returned to end his days where they began, — where, with perhaps some faint forebodings of what his fame might be, he lived on without any apparent concern for a thing of so little real value, — perhaps a happier man than he would have been, had he possessed in life all that posterity have awarded him in death.

This afternoon I have found a treasure in the person of Dr. Sweetser, who arrived here about a week since, having been wandering "to and fro in France, Italy, and Germany, and walking up and down therein." He is in good health and spirits, and I think will return with me in August. Will not the ship have a "bonnie freight" that brings *twa sic chiels* as S. and T.? I shall get through with everything to leave here by the 1st of August. . . .

Ever yours,

DANIEL TREADWELL.

To Dr. John Ware.

London, July 9, 1835.

My dear Sir, — I received yours by Mr. Ticknor, and likewise another from you by the packet of the 16th of June. Your letters, although relating to ordinary events, produced a sensation in reminding me of your habits of philosophical thinking, which, let me say, I do not often fall in with here, much as I see, otherwise, that is admirable in science and in the arts. You are somewhat melancholy, and more than usually inclined to thoughts of a religious character. You know that it has always been a standing wonder with me, that those who *believe* should ever think or act without reference to their belief, as everything of this world is of so little importance compared with that which a believer must anticipate of the next. It must indeed be a glorious imagination for one to suppose himself here but entering upon a series of perceptions which are to be continued and accumulated in other states, to which this life is but the dark passage. To believe that the great mysteries which we here grapple with for a while, and then abandon in despair, will be made as plain as our easiest knowledge is to us now, — to believe that we shall see relations existing between appearances which at present seem arbitrary and even incompatible, — all this, if it could be obtained, would indeed be worth striving for. But what labor will attain it? what price purchase it? You have often said that if this life were *all*, you should think it not worth the possession, and it would pass without enjoyment. You know not the law of your nature. If you thought it final, you would strive to make the most of it, and perhaps enjoy it in itself, considered apart from your hopes of the future, more than you do now, in the same way that a poor man gets enjoyment from his little that he would despise if he had a great estate in prospect.

I have written so much to Adeline of my *travels* that I shall not go over that ground again with you. I have found great difficulty in getting away from common sight-seeing, and getting at that which I came out to see. Wherever I have gone, the water-falls, the landscapes, and the pictures have been pressed upon me by every one with whom I became acquainted, and I have been obliged to give time to running after them against my will. At the same time, the iron-works and cotton-mills have been hard to come at, not being objects of attention to *gentlemen travellers*, and I have been obliged to grope my way to them without the aid of a guide-book.

July 18. — I suffered the preceding to lay over from day to day until it was too late for the packet of the 16th. I now sit down to finish it for the 24th. Dr. S. is here, having been over a large part of the Continent. He is, of course, unchanged in his disposition and modes of thinking, so that you can judge how he takes things. I shall only say that amongst the excellent points of his character the following little defects appear more strongly than ever: first, a proneness to generalize from a single example; and secondly, when he advances a little farther and finds a second example to contradict his first, to doubt whether anything like truth is to be arrived at. He will leave London next week for Scotland, and embark at Liverpool on the 8th of August for New York. Mr. and Mrs. Ticknor are hand and glove with the aristocracy. I am glad that this is so, because, so far as it is important that Mrs. Grundy should think well of us, Mr. T. is a man to advance us in the old lady's estimation. I am *tired with sight-seeing, and distracted with the changes to which I am constantly subjected;* the more, perhaps, because I constantly feel that all that is now about me is really of no consequence to me, that it might all perish without affecting me, and that it is to be looked upon as a show of *jugglery*, in which I can have no interest but that excited by curiosity to see how the wires are arranged to produce such complicated movements. Feelings of this sort, perhaps, come over one at home, and surrounded by his common associates, and are only lost in the closer affections for wife and children.

You are not probably sensible in Boston that there is anything going on here of more importance than usual, and this is probably the truth; and yet a superficial observer here thinks that the Irish Church Bill and the Municipal Reform Bill are of more consequence than all the political measures that have preceded them. Perhaps, even, the great politicians are excited to the same opinion; but this is, in truth, a mere continuation of interest by the living race in little measures of which history furnishes a continued series, which have in turn been considered of all-absorbing importance in their time. The Americans are much better known to well-informed people here than they were when I was in England in 1820, and the importance of commercial relations is more highly appreciated. The character of our writers likewise stands higher. At the head of these is Dr. Channing. I had no idea that he was so generally known among the English as I find him to be: perhaps I have fallen in with an unusually large proportion of Unitarians. Dr. Tuckerman likewise made himself known to a great many people, and is remembered and highly respected. I am not a little vexed, however, at the reputation assigned to that poor dog Cooper, the novelist; his books have been very generally read, and have made a wide impression; as proof of this, let me tell you that I came up from Liverpool in a line of coaches called the "Red Rover" coaches.

In the autumn of 1835 he returned from Europe, and went immediately to Cambridge to prepare for his lectures in the College.

When Mr. Treadwell received his appointment, Professor John Farrar, as Hollis Professor of Mathematics and Natural Philosophy, had taught since 1807 branches closely allied to those of the Rumford Professorship. Professor Farrar entered upon his duties at a time when there was very little learning in the country in mathematics and physics. Webber's Mathematics and Enfield's Elements of Natural Philosophy were the only college text-books on these subjects. He first prepared himself to become a fitting teacher, according to the French standard of the age. Before 1818 he published his translation of Lacroix's Elements of Algebra. This was followed, in the course of nine years, by translations and compilations which placed in the hands of his class the works of the best French writers in his department. These treatises were adopted for the course of instruction, not only at Cambridge, but at the United States Military Academy and other principal institutions of learning throughout the country. For the work he accomplished in raising the standard of mathematics and physics, and preparing the way by which others might reach far superior heights, he merits great praise.

As a lecturer Professor Farrar was among the very best in any department. The apparatus of those days was without instruments of precision, and wholly inadequate for nice and intricate demonstration. But he had the power of vivid description, fluency, and grace, and an easy mastery of the subject, and of the expressions best suited to convey to his pupils that at which he aimed; "and above all," says President Felton, "a singular enthusiasm, poetical coloring, and eloquence, with which he knew how to illuminate the truths of science, to which we listened with a never satiating delight, and which gave a fascination to his lectures difficult to describe."

He was the Recording Secretary of the American Academy for thirteen years, its Vice-President, and a member of the Committee of Publications. He died in Cambridge in 1853. The Academy at its first meeting after his death, on motion of Professor Lovering, seconded by Professor Peirce, passed a resolution gratefully recognizing his various official services to the Academy, and his valuable contributions to science in the flower of his life. "We remember still the poetical ardor with which he cultivated his favorite sciences, the fervor and enthusiasm with which he taught them, and the rare fascination and eloquence with which he discoursed upon them. We also remember the silent eloquence which beamed from his countenance in sickness, and even in death. For his rich intellectual gifts and his

Christian dignity and courtesy, which many of us enjoyed so long, we would ever hold him in grateful remembrance."

Professor Treadwell says of his acceptance of the Rumford Professorship: —

> "I accepted this place rather against my inclinations, and with the suspicion that I was not exactly suited for it. I was a stranger to college life, its associations, customs, and traditions, unacquainted with some branches of learning, especially the ancient languages, that form, and I believe very properly, a principal part of college study. But the courtesy and kindness of the Professors soon relieved me in a degree from the disagreements of my false position. Those whom I had not known now became my friends, and I found myself in a society more exclusively intelligent and gentlemanly than I had ever been connected with before."

His friends had no such misgivings; they knew his high intellectual powers and his abilities. His lectures were remarkable for their choice English, clearness of description, precision in the enunciation of propositions, logical sequence of ideas, and well selected and successful experiments. Few lecturers could exceed him in ability to fix clearly and permanently in the minds of his pupils the subjects of his teachings. He filled the chair with great honor to the College till his resignation, in 1845. The subjects of the lectures were as follows: Introduction; Properties of Matter; Forms of Materials; Materials; Simple Machines; Friction; Steam and Steam-engine, five lectures; Water-Wheels, two lectures; Lathe; Last-Machine and Hydrostatic Press; Railways, two lectures; Cotton Spinning and Weaving, three lectures; Architecture, three lectures; and Time-keeping.

His lectures required but a part of his time, and by the terms of his acceptance of the office he was left free, when not lecturing, to engage in other pursuits.

On November 26, 1835, Professor Treadwell was, with Mr. Henry G. Rice, appointed by His Honor, Lieut.-Governor Armstrong, under a Resolve of the Legislature of the Commonwealth of Massachusetts, the first on a commission "who, with the Treasurer and Receiver-General, shall cause the standard weights and measures of the Commonwealth to be carefully examined, and their inaccuracies corrected, or shall supply the places of the imperfect weights and measures by new and accurate ones as they shall deem expedient, and they shall further procure, to be used as public standards, a new set of weights, . . . and they shall give the preference to such weights and measures, used by the Government of the United States, as they shall find to be accurate, . . . and they shall make a detailed report of their doings to the Legislature as soon as may be."

In January, 1837, Mr. Treadwell, as chairman, reported that immediately on their appointment they made an examination of the weights and measures in the Treasurer's office, and found such disagreements between the several weights as to render them totally unfit for standards. An equal disagreement was found among the measures of capacity. The rod which has been used as the standard of the yard and ell, the only standard in lineal measure in the treasury, had been broken, and reunited in a manner which had evidently increased its length. It further appeared to the commissioners, that all the weights and measures were objectionable in form, and imperfect in workmanship. They had, moreover, all been injured by corrosion, and by long and careless use.

Having learned that Mr. F. R. Hassler had been employed by order of the Secretary of the Treasury in preparing for and making standard weights and measures for the supply of the different custom-houses, and had in his possession a weight, being a *troy pound*, corresponding exactly with the pound of the English Exchequer, and a yard measure corresponding with the British parliamentary standard of 1758, one of the commissioners proceeded to Washington and procured from Mr. Hassler a troy pound certified by him to be identical in weight with that of the United States Mint, and likewise a pound avoirdupois weight, certified to contain 7,000 grains of the troy standard. These were duplicated by competent persons in Boston. They were carefully examined by the commissioners, and found by them to exhibit as near an agreement with the weights made by Mr. Hassler as was attainable without a refinement of instruments and of workmanship to be procured only at an expense which the commissioners did not consider themselves authorized to incur. They were considered as deserving of entire confidence as standards. Application was made for a copy of the standard yard, but it had not been obtained when the commissioners made their report.

In the course of the investigations upon which the above report was founded, it was discovered that a discrepancy of one twentieth of a grain existed between the troy pound furnished by Mr. Hassler to the committee, and that furnished by him to the custom-house. This produced considerable discussion between Mr. Hassler and the committee, which terminated very clearly in favor of the committee.

In 1837, Professor Treadwell was solicited to take charge of the Amoskeag Mills, then about being built on the Merrimac River, at Manchester. The duty of laying out and building canals, erecting factory buildings, and all the work attending the beginning of extensive manufactories, would of course devolve upon him. He declined, although the salary offered was very liberal, as appears by the following letter: —

Boston, February 20, 1837.

Dear Sir, — I have given to the proposal made to me by Mr. Lowell and yourself, that I should take the charge of the business of the Amoskeag Company, all the attention which its importance demanded for it, and I am unable to avoid the conclusion that I ought not to accede to it. Suffer me to state to you some of the reasons which have brought me to this conclusion. It seems to me of the utmost importance that the agent of the company should be made answerable in his interests and his reputation for the *success* of the company; — not merely for discreet management without obvious mistakes, but for *success*. To encounter this responsibility he should give his whole time and strength to its concerns, without distracting his attention from this to any other object. Now I cannot devote myself in this way. I have several other objects to which I am bound in honor, inclination, and profit (my place at Cambridge is not connected with the last of these) to give my attention. You suggest, however, in your letter, that the business of management may for the present, at least, be divided, — that a portion may be assigned to a superintendeut residing at Amoskeag, and another portion to a treasurer residing here. This would undoubtedly free the manager, or by whatever name he were called, from much labor; still, it would be that part only which would weigh least heavily upon him, and if his heart were in the service which would remain to him, he would find his whole attention drawn to it, even against the efforts of his will. I know my own disposition, and I am certain that, with the pressure of my other avocations I should either neglect your affairs, so as to be constantly dissatisfied with myself, or I should sacrifice other pursuits, to which I am attached by their merits and by long acquaintance, and to which, moreover, I am bound by actual engagement. Under the first of these conditions the company cannot desire my services, and I ought not, for my own sake, to risk encountering the second. In conclusion, permit me to remark that the salary understood to have been proposed is in my opinion all that any one could ask, and, were I to engage in a service of this kind, there are no men in the community that I should prefer to you and your associates as those to whom I should be accountable.

Daniel Treadwell.

Mr. Treadwell likewise received the following communication this year, asking his aid in the construction of the Water-Works: —

To Daniel Treadwell, Esq.

Boston, January 31, 1837.

Dear Sir, — It is with great pleasure I announce to you your appointment as one of the commissioners for the introduction of a supply of pure water into the city. Your associates, should you and they accept the appointment, will be P. T. Jackson, Esq. (the first named) and J. R. Adan, Esq. Allow me to express the hope that you will not refuse to perform this great service for the community, and that you, together with the other distinguished gentlemen named, enjoying, as you do, the public confidence, will be instrumental in procuring for the city the inestimable blessing of an abundance of pure water. If you will call at the Mayor and Aldermen's room, I will show you the rules adopted by the committee for the guidance of the commissioners, which are merely such as would at once occur to you. The compensation is eight dollars a day for each commissioner.

With much respect, I am yours, etc.,

Samuel A. Eliot.

After a good deal of discussion he accepted this appointment, and the commission was two months later arranged with Mr. Treadwell as chairman; the other commissioners were Colonel James F. Baldwin and Hon. Nathan Hale. Their report has already been given, at page 355.

In 1837 the College Library had quite outgrown the capacity of Harvard Hall, and another building, better suited to its administration had become a necessity. Plans had been made by Mr. Richard Bond, an eminent architect, who had taken as his model for the exterior King's College Chapel, at Cambridge, in England. "On entering Gore Hall," says President Quincy, "we are presented with two ranges of columns, ten in each range, which rise from the floor to the ceiling. This open space resembles the nave of a small cathedral, 112 feet long and 35 feet high. The ceiling is formed of groined vaults, ornamented by ribs rising from the columns and intersecting each other in various points. The appearance of the whole is imposing; hardly surpassed in effect by any room in this country. . . In the construction of this edifice, it was determined at the outset to use every precaution which the funds of the College would allow to guard the library from destruction by fire."

The construction of a building of this description, which should afford a large ornamental hall for the meetings of the Alumni, a library for the arrangement, storage, and delivery of books, and at the same time, with limited means, be guarded from destruction by fire, was indeed a difficult problem. To solve this problem, the Corporation, by vote on the 19th of January, 1837, "requested Professor Treadwell to superintend the erection of the new library, with such assistance as he may require, a liberal compensation being allowed for his services," and the following communication was made to him by T. W. Ward, Esq., Treasurer of the College.

BOSTON, January 21, 1837.

MY DEAR SIR, — It is so important, in every view, to have your services, (and I may add almost indispensable,) that I cannot doubt you will comply with the wishes of the Corporation and accept the superintendence of the building. You can have any assistance you may require or desire, and I shall be greatly obliged by hearing from you in the affirmative.

Dear Sir, very truly yours,

T. W. WARD.

Professor Treadwell, on accepting the office, found the plan and method of construction of the interior already fixed. All the ornamental mouldings, the groined arches, and their ribs, were of plaster, without wooden foundations, and so far favorable for resisting heat. The ceiling, thirty-five feet from the floor, was of plaster well secured to the laths, which were held by light joists without beams or floors, offered little food for flames. The gallery floors were supported entirely by bars of wrought iron, and guarded by a light iron balustrade. The two ranges of Gothic columns, of brick, supporting the roof, and for that purpose rising from the foundations in the cellar through the ceiling, were as safe from fire as could be desired. The walls, which were furred, lathed, and plastered, were objectionable; in the spaces between them and the stonework fire could spread, even if that space were cut off from floor to floor by incombustible materials. The window-frames were to have been of iron, but wood had been substituted.

The first condition for safety was the placing of the heating apparatus where it would be effectually cut off from the main hall of the building. This was done by making the floor of the hall of a series of groined vaults of brick, supported upon large square columns; through this the only openings were for the steam-pipes for heating. The whole ground was damp, the arches were low, and the windows small; consequently, without inducement to place here woodwork or inflammable matter of any kind to interfere with the sole purpose to which the cellar was to be devoted, namely, the heating apparatus. The cellar of the west transept, which is vaulted, like the cellar of the main building, contained a small hot-air furnace, and a narrow flight of stairs, the only communication with the room above. The spandrels of the arches were filled up, and upon them is laid a single floor of hard pine.

The roof is constructed without wood, except the boards or laths to which the slates are fastened. The place of rafters is supplied throughout by trusses made of light bars of wrought iron, which are supported by the walls and by iron purlins ranged through the building upon the tops of the Gothic solid brick columns, which rise from their foundations in the cellar through the ceiling for this purpose. The thrust of these trusses is prevented by iron rods, which take the place of the beams in wooden roofs. Its weight is about half that of a wooden roof of the same size, and equal to bearing the weight of a body of men standing close to each other, and covering a space as great as that enclosed by the building. The attic has no floor, and therefore affords no place for storage.

In selecting a heating apparatus, Professor Treadwell was strongly in favor of steam as the vehicle. Hot air and hot water were both considered. The first, although the simplest and at that time generally used for houses, is objectionable. Its dryness and deleterious gases are difficult to avoid. They are apt to injure the binding of books: the leather becomes dry and brittle, the covers are warped, and if much used soon break. It often contains smoke from within, and dust from without, and from ashes sifting through the cracks and joints, settling everywhere. If admitted through large openings in the floor, these become a source of danger. The heated column in a room like the library hall would rise directly to the ceiling, where it is least wanted, and escape through the porous plaster and the windows, with little benefit to persons on the floor. Hot air affords no radiant heat, and is costly as a vehicle of heat. Hot water, except in the regularity of its working temperature, has few advantages over steam; the apparatus requires more skill in construction, and is more costly, than for steam. Steam-heating, nowhere common at that time, was generally used in the large rooms of factories. Steam was adopted for the heating of Gore Hall, and from the Lowell Mills were obtained the principal data for this purpose.

An iron boiler thirty inches in diameter and eighteen feet long was placed in the cellar on the east side of the building, connected with a large chimney built for the purpose in the outer wall. Steam was led from this boiler, in an iron pipe six inches in diameter, along the arches of the vaults to four points, two on each side of the hall. From each of these a smaller pipe reached a collection of fifty pipes in the hall above, arranged in a stack ten feet long and eight feet high, with a radiating surface of 286 square feet. Each pipe had within it an air-pipe one quarter of an inch in diameter, which joined others below the floor and ended in the chimney. This method of drawing off the air from steam-pipes was probably first used here. The total radiating surface, 944 square feet, was in excess of the steam-making power of the boiler, and of the space to be heated, 171,400 cubic feet. The apparatus was worked at atmospheric pressure only. Steam passed from the boiler through the six-inch pipe to the radiators, and the water of condensation returned through the same pipe to the boiler. The expansion of the air pipe moved a damper in the chimney, and controlled the fire. The temperature of the hall was in the coldest weather about 60°, and evenly distributed.*

A stone building with an iron and slate roof, in an isolated position, and never artificially lighted, gives reasonable assurance of safety from without. With an interior of lath and plaster, Gore Hall would be classed as "slow burning," but by

---

* January 2, 1849, the external temperature at evening was —2°, the next morning —4°; at 10 A. M. +10°. On that day the thermometer, five feet above the floor of Gore Hall, about 1 P. M., was 56°; at the ceiling directly above, 62°; at west transept at ceiling, 61°; five feet above north gallery floor, 64°. With an external temperature of 41°, that of the cellar was 76°, which probably raised somewhat the temperature of the floor above. The heat radiated from the large masses of steam-pipes was found to give a degree of comfort to persons in their vicinity not obtained from warm air alone. The coal consumed was about fifty tons of anthracite annually. In simplicity of construction, safety, and economy, it has not been excelled. Steam-heating has proved satisfactory to the present time in the Library of 1837, nearly half a century, and was adopted in the addition of 1878.

no means as "fire-proof." A strictly fire-proof building is one into which no wood enters, either in floors, doors, windows, or shelves, and very little furniture.*

The stone for the foundations furnished by the contractors was a disintegrating sienite. It had been used in the foundations of the meeting-house of the First Parish in Cambridge, and was already crumbling into a coarse gravel. This Professor Treadwell rejected, and substituted granite from a quarry in Quincy owned by President Quincy. Subsequently the stone from the same quarry was selected for the whole building, for which it was eminently fitted. This drew from Mr. Quincy the following letter, quite in keeping with his old-fashioned integrity.

---

* Although not the architect, Mr. Treadwell felt the responsibility which rested upon him as superintendent of building, and knowing that some points in the construction had not, after fifteen years, been carried out, again called the attention of the President to the facts in the following letter, dated Cambridge, May 28, 1852: —

"Dear Sir, — You may remember that several years ago I called at your office and stated to you that the partitions of the alcoves over the Librarian's room in Gore Hall were formed of trusses which supported the gallery; that according to the original design of the building these trusses were to be themselves supported by small iron pillars, to rest upon the piers built in the basement, and pass through the Librarian's room to the ceiling. The construction of these pillars was neglected at the time the building was finished, from the pressure of other things, and because it was well known that the trusses possessed ample strength for the support of their load so long as the wood should remain sound. I furthermore stated to you, that I thought the pillars ought then no longer to be neglected; that whenever the ends of the trusses which enter the walls and the large main columns of the building should become decayed, the trusses and partitions would fall, and might possibly thrust the main pillars inwards. To destroy them would bring down a portion of the iron roof of the building. Now as those who shall occupy the building after the present generation will not be likely to know that any pillars were designed or required for its support, any longer delay in causing them to be made and put up may involve, not only a great injury to the building, but a great destruction of life.

"At the same time that I made the above relation, I furthermore stated to you, that it had recently been found that the smoke or products of combustion of anthracite had in many instances affected injuriously the mortar of the flues through which it passed, and that therefore the main flue of Gore Hall ought to be thoroughly examined, and, if found in the least wanting in adhesiveness or solidity, that the flue should be lined with cast iron or bronze, either of which might be put in without any great cost, and would render it entirely secure. I was aware that this might seem like over-caution, but I thought that the character of the property at risk warranted it, as no money could replace many of the books which would be destroyed if the building were burned. I have thought it my duty again to call your attention to these subjects, and in this formal manner, and I beg you, if you do not think them worthy of being acted upon, to file this letter with the Corporation, to make the matter so known to the Honorable and Reverend the President and Fellows, that I may not in any case be considered responsible for what may come hereafter.

"May I trespass upon your indulgence a few words more? When Gore Hall was building, and before the towers were finished, I perceived that, if they were raised to the height shown in the model and plans, which had been made and adopted before I had anything to do with the building, they would be much too lofty for the body of the edifice. I compared them with the plates of King's College Chapel, from which the design was taken, and computed with some labor the comparative proportions of the buildings, with the height of the towers of each, and found that those of Gore Hall would be eight or ten feet above the true proportion of King's College Chapel. Upon this, I procured a meeting of the building committee with Mr. Bond, the architect of the building, to attend it, and proposed, for the reasons above given, that the towers should be curtailed in the proposed height. This was opposed by Mr. Bond, and, *not a single* member of the committee agreeing with me in my views, the towers were of course carried to the altitude given in the model and plans."

When completed, it was obvious that Mr. Treadwell was right, and some years after the towers were reduced in height as he proposed.

To DANIEL TREADWELL, ESQ., *Rumford Professor.*

CAMBRIDGE, October 7, 1837.

My dear Sir, — In the many public offices I have held, and in which I have necessarily been the agent for making contracts, on the part of the public, to very great amounts, one principle I early adopted, to which, through my whole life, I have strictly adhered; *never to give any direction to any contract made on behalf of the public, directly or indirectly, proximately or remotely, to my private advantage.* It is among the possibilities of future events that the stone of this quarry may not prove satisfactory to the public taste, or that the contractors may not execute well their undertaking, or be dilatory in performing it, in any of which cases the malignity or jealousy of mankind may attribute the selection of the stone or of the contractors to my influence, or to a desire to promote my interests. I wish, therefore, at this stage of the affair, to have a direct statement from you on the point above alluded to. I do not know that the contract is signed, but if it be signed, no work has as yet been done in relation to the completion of it, and I had rather indemnify these contractors to the full amount of any imagined benefit they expect to derive from fulfilling this contract, and induce them to abandon it by paying them out of my private purse, than have a single individual of fair mind imbibe the idea that I had been in the slightest degree instrumental in obtaining for these lessees this contract.

My request, therefore, to you, is to reply directly and conscientiously to the following questions, in writing, so that I may possess hereafter a document, which, as far as in the nature of things is possible, shall enable me, if necessary, to repel any such jealousy or malign suspicion, should they occur: —

1. In selecting the quarry, or in accepting the contract, *has the fact that it was mine had the slightest influence* upon the ultimate decision?

2. In the course of all the transactions preceding the selection of the quarry or accepting the contract above mentioned, has anything I have done or said indicated an intention to produce any influence in favor either of the one or the other?

I request a direct and unequivocal answer to both those questions, and that it may be given in the most perfect simplicity and singleness of heart. For however unconscious I may have been of the intention, such influence may have been effected, resulting possibly from my mere relation to the subject, in which case I wish now to be apprised of the fact, that, while I yet probably can, I may take such measures as may relieve me from a possible responsibility hereafter, which to me, if it occur, will be very heavy.

Respectfully, your humble servant,

JOSIAH QUINCY.

Professor Treadwell was requested by Hon. Nathan Hale, President of the Boston and Worcester (now Boston and Albany) Railroad, to investigate the effect of a device affixed to the chimney of the locomotive to prevent the escape of sparks from the burning fuel, which had become a source of annoyance, and even danger, to the passengers. The apparatus answered the purpose intended, but was thought to diminish the power of the engine.

As this investigation would require careful observation, it was determined at the same time to obtain facts for the solution of other questions, such as the comparative powers of engines of different dimensions and forms of construction; the comparative power of the same engines using steam of a given elastic force when running at different velocities; the quantity of wood required to produce a given power; the resistance of the load when passing upon a horizontal plane, and upon ascents of different inclinations, and likewise the effect of the curves of the railway in increasing the resistance; and any other facts important to the constructive arrangement or management of railroads or locomotive engines. These investigations were made the subject of an elaborate report, in March, 1837, which will be found in Appendix II.

In 1838, Professor Treadwell was appointed by the Secretary of the Treasury of the United States, together with Dr. Jacob Bigelow, Alfred Greenough, and William Sturgis, on a commission for the purpose of superintending the experiments in relation to lights in light-houses. But this appointment was declined.

Professor Treadwell still retained his connection with the Boston Hemp and Cordage Company, which grew out of the successful operation of his machines; he was its agent for conducting a large business in spinning the hemp, in manufacturing cordage, and in constructing machines for the Government, and for many of the large manufactories. Indeed, it was the income from these sources that enabled him to accept the Rumford Professorship, from the funds of which he received but about eight hundred dollars a year.

In 1840 he had already been considering the practicability of constructing cannon of greater strength, and consequently of greater calibre, than those in common use. Count Rumford had long before turned his attention in the same direction, but his experiments were limited to the use of cast iron, modified by a new method of casting by which its tenacity was very much increased. The thoughts and labors of the Rumford Professor were destined from this time to be directed to the same subject for the greater part of his active life. He had by long experience in the manufacture of machinery learned the properties of metals; he had studied the forces to which they are subjected when used as materials for cannon, and saw the advantages to be obtained by the substitution of wrought iron and steel for bronze and cast iron.

In 1845 he published "A Short Account of an Improved Cannon."* The following extracts will show the course of reasoning which led to the invention of the

---

* This account was reprinted in 1865. It was translated into French in 1848, with the title, "Notice succincte sur un Canon Perfectionné et sur les Procédés méchaniques employés à sa Fabrication, par Daniel Treadwell. Traduction de M. Rieffel, Professeur de Sciences appliquées à l'Ecole d'Artillerie de Vincennes." Paris, 1848.

improved cannon, the processes of manufacture, and the efforts he made to bring it to the favorable notice of the government.

“Having been engaged more than four years in inventing and reducing to practice a method of making cannon of wrought iron and steel, which have been proved, by the most severe tests, greatly superior to cannon made of bronze or cast iron, I have thought that a general account of my mode of operation, and of the principles and laws upon which it is founded, may not be without interest to engineers.

“The first cannon made after the invention of gunpowder were of wrought iron. They were commonly formed of staves and hoops united together by brazing. These engines, it seems, answered for throwing light projectiles, as stone balls, the powder probably being much inferior to that now used with artillery. It is certain, however, that none of the old wrought-iron cannon made in this way would withstand a single discharge if loaded with modern powder and solid iron shot. The early abandonment of these guns, and the substitution of those made of bronze and cast iron in their place, does not prove, however, that the material was inferior to bronze or cast iron, as it is evident that this mode of construction must, in itself, be essentially defective. No fact in the arts seems to be more confidently relied upon, than that wrought iron is much stronger than cast iron or bronze, and this is certainly true if we expose the wrought iron to the testing force in one particular direction only. But all wrought iron is in its structure fibrous, the fibres being more or less distinctly marked, according to the process followed in the manufacture of the iron. In wire it is most clearly apparent, the fibres, in some cases, being so easily parted that the wire can be split with a knife. In sheets, formed by the rolling-mill, the fibres are arranged in plates or laminæ, and these often so slightly adhere one to another that they may be separated like the layers of a pasteboard. With hammered iron, the grain or fibres are less apparent, and the bars possess, in their different directions, greater equality of strength. By comparing the various operations of wire-drawing, rolling, and hammering, we are led to the conclusion that the fibres are always formed in the direction in which the iron is extended, and the cohesion is least amongst the atoms which are spread over each other. All that is here said of iron is equally true of steel, the cohesive force of which, however, exceeds in an essential degree that of iron. Cast iron and bronze, on the contrary, are of equal strength in all directions; their structure appearing as an aggregation of grains, assuming the form of crystals, often apparent to the naked eye.

“The strength or direct tenacity of these various metals, the wrought iron and steel being tested in the direction of their fibres, may be taken as follows for each square inch area of the metal: —

Steel (English spring)	100,000 pounds.
Wrought iron	65,000 “
Bronze	30000 “
Cast iron	25,000 “

That is, a bar of steel of one inch square will raise and sustain a weight of 100,000 pounds, and bars of wrought iron, bronze, and cast iron, of 65,000, 30,000, and 25,000 pounds, respectively. This statement, supposing all the materials of good quality, is a near approximation to the truth, as derived from the best experiments. If, however, the steel or wrought iron be exposed to the testing force in such a way that the fibres shall be separated laterally instead of being broken, the strength will rarely be found to exceed that of bronze or cast iron even.

" By attention to the preceding statement, we see that two distinct questions are brought up for examination. First, Does the expansive fluid, formed of fired gunpowder, exert an equal force in every direction? and, secondly, Does a cannon, of the usual form, present in every direction an equal area of metal, acting with an equal mechanical advantage, to be torn asunder before the fluid can escape? We may, I think, for all practical purposes, take it as true, that the expansive force of fired gunpowder is equal in all directions, and that, consequently, no advantage could be gained by giving any particular direction to the fibres of the wrought iron of which a cannon should be made, depending upon the force of the fluid being less in one direction than in another.

" To answer the second question, namely, Does a cannon of the usual form present, in every direction, an equal area of metal, to be torn asunder before the fluid can escape? we shall find it useful to resort to numbers, and apply them to a form as an example. For this purpose, let us suppose that we have a hollow cylinder, say twelve inches long, the calibre being one inch in diameter, and the walls one inch thick, giving an external diameter of three inches. Suppose this cylinder to be perfectly and firmly closed at its ends by screw plugs, or any other sufficient means. Let this be filled with gunpowder and fired. The fluid will exert an equal pressure, in every direction, upon equal surfaces of the sides and ends of the hollow cylinder. Let us next examine the resisting power of a portion of this cylinder, say one inch long, situated in the middle, or equally distant from the ends, so that it shall not be strengthened by the iron which is beyond the action of the powder. The fluid, enclosed by this ring of one inch long, contains an area of one square inch, if a section be made through it in the direction of its axis; and the section of the ring itself, made in the same direction, will measure two square inches. We have then the tenacity or cohesive force of two square inches of iron in opposition to an area of the fluid measuring one square inch; and if we take the tenacity of the iron at 65,000 pounds, the cylinder will not be burst, in the direction of its length, unless the expansive force of the fluid exceed 130,000 pounds to each inch. Next, let us suppose a section made through the cylinder and fluid transversely. The area of the fluid, equal to the square of the diameter of the hollow cylinder, is one circular inch, and the area of the whole section is, the diameter being three inches, nine inches. Deduct from this the area of the calibre, and we have eight circular inches. That is, the section of the iron is eight times greater than that of the fluid; whereas in the former case of longitudinal section the iron gave but twice as much surface as the fluid, and if we take, as before, the iron at 65,000 pounds per inch cohesive force, it will not be broken unless the force of the fluid exceed 520,000 pounds. It will be found, upon a further examination, that the relations of these sections to each other may be varied, as we take the diameter of the calibre to be greater or less, as compared with the thickness of the sides, but their difference can never be made less than as two to one. Here then is a principle, or rather a fact, of the utmost importance in forming cannon of any material, the strength of which is different in different directions; for as a cannon made in the proportions above specified, if the materials be in all directions of equal strength, will possess four times as much resistance to a cross fracture as it does to resist a longitudinal fracture, it follows that a fibrous material which possesses four times the strength in one direction that it does in another will form a cannon of equal strength if the fibres be directed round the axis of the calibre. It is this fact which gives the great superiority to the various kinds of twist gun-barrels. For in these, although the fibres do not inclose the calibre in circles, yet they pass around it in spirals, thus giving their resisting force a diagonal direction, which is vastly superior to the longitudinal direction in which the fibres are arranged in a common musket-barrel.

> "Having been aware of the fact here stated, and, I trust, in a manner which can be easily understood and appreciated, for many years, I determined, between four and five years ago, to attempt to apply it, practically, to the fabrication of cannon. My first attempt was to make a four-pounder cannon, by the best means then at my command, of rings, or short hollow cylinders joined together end to end by welding. Each ring was made of several thinner rings, placed one over the other and welded. It will be seen, that, in this case, as the bars of which the several rings were formed were curved round the calibre, the direction of the fibres herein shown to be so essential, was fully preserved. I may remark here, that this method was subsequently changed in some degree, by first making a single thin ring of steel, and upon the outside of this winding a bar of iron spirally, as a ribbon is wound upon a block. This gun, although imperfectly made, withstood the action of enormous charges of powder, and was only burst by using very superior powder, and shot without windage. The fracture was made lengthwise of the gun, or across the fibres of the iron; and although the welds (technically called jumps), which united the rings to each other endwise, were most imperfect, they yet held together completely against the action of the powder. Two other cannon of similar kind were subsequently made, one of which yet remains uninjured, after having withstood many most severe tests."

Having this experimental proof of the strength of cannon made in this form, and being satisfied that the principle upon which he wrought is true, he determined to carry it beyond the stage of experiment, and, as he hoped, into successful practice. To do this, however, required engines and tools of an elaborate and costly kind, as the large amount of money already spent fully proved, and also some assurance that the guns produced would be adopted by the Government.

He therefore filed a caveat, in which he gave notice, in a general way, that he had invented and reduced to practice a method of making cannon of wrought iron.

> "But wishing further time to mature and perfect said invention, I hereby in this caveat specify and set forth the design and purpose of my invention with its principal and distinguishing characteristics, that the same may be protected according to law. My method of making cannon or great guns to be mounted by their trunnions upon carriages is as follows. First, I form rings or hollow cylinders of wrought iron by bending bars of iron around a proper mandrel of the required size, and welding their ends together by a *scarfed* joint. These rings are to be of the thickness required for the walls of the cannon at the part where they shall be placed, and of such length as shall be most convenient to handle and work, — say about equal to their diameters. Having made such numbers of rings as when placed end to end shall be equal to the length of the cannon required, I weld them together endwise so that they form one cylinder, which with the trunnions and other appendages shall constitute the cannon. . . . Again, in forming the rings of many thicknesses, instead of forming complete rings, as before described, the iron may be wound upon itself after the manner of winding a ribbon upon a block."

The remainder of the caveat describes several ways in which the iron may be arranged, and some general directions as to the manufacture. It is dated at Boston, June 19, 1841.

To obtain the assurance of Government aid, Professor Treadwell, in March, 1842, went to Washington.

"I laid the subject before the Secretary of War, then Mr. Spencer, who very properly referred it to that very competent officer, Lieutenant-Colonel Talcott, Chief of the Bureau of Ordnance. This gentleman, whose knowledge in everything belonging to the use of cannon is probably not equalled, certainly not surpassed, by that of any man in the country, was at first disposed to regard the project with disfavor. He had, several years since, made some experiments in firing a small wrought-iron cannon, made of a large, solid bar of wrought iron, formed under a forge hammer, by a process somewhat like that of common fagoting. This gun, although not burst by the charges to which it was subjected, was sensibly enlarged in its calibre, thus showing that the iron did not possess the hardness required to withstand the enormous pressure of the fluid. On informing Colonel Talcott of my proposed method of manufacture, however, and likewise that it was my intention to make the inner portion of the cannon of steel, he assented to the probability of success, and recommended to the Secretary of War to authorize a contract for a few six-pounder field cannon, which contract was forthwith made. The Secretary of the Navy likewise, Mr. Upshur, directed a contract to be made for four light navy thirty-two-pounder cannon."

He thus writes to Mrs. Treadwell of the difficulties in his way, and of his hopes: —

WASHINGTON, March 5, 1842.

Dear A——, . . . I arrived here on Wednesday at sunset, and on Thursday morning began business, and have ever since been in great excitement about it. I shall have much to tell you of what has risen against me, and how I have laid myself to overcome the opposition. I will say now that I have the promise of a contract with the War Department for six small pieces for them to make a fair experiment with, and I am satisfied that it will have a fair experiment. Colonel Talcott, the Chief of the Ordnance, with whom I have made the negotiation, is an honorable and high-minded man, and I have every reason now to be satisfied with the state of things with him. Colonel Talcott thinks I shall not get a contract with the Secretary of the Navy, but that he will wait to see the result of the experiment with the War Department. . . .

WASHINGTON, March 7, 1842.

All is going well; the contract is made, all but signing, with the War Department, and I am now maturing one with the Navy for *four thirty-two-pounders.* Magnificent! I owe my success to Colonel Talcott, who wants to see the guns fairly tried. Yours truly,

D. TREADWELL.

TO COLONEL GEORGE TALCOTT.

WASHINGTON, March, 1842.

Sir, — At the close of the interview with which you favored me on Monday last, you desired that I should call upon you after I should have arranged my contract concerning improved cannon with the Navy Commissioners. Having now completed this contract, and finding you constantly engaged with others when I have called at your office, I am obliged to leave the city without again paying my respects to you in person. I cannot, however, depart without expressing to you my high sense of the prompt and unprejudiced manner in which you acted upon my proposals. Whether I shall be ultimately successful or not in my project can only be known by experiment. This shall now be fully tried; if it fails, I shall not mourn over it, and you will forget it; but should it succeed so as to become of importance or interest to the public, I shall take care that your ready encouragement of it be publicly known.

DANIEL TREADWELL.

To DANIEL TREADWELL, ESQ., *Cambridge, Mass.*

ORDNANCE OFFICE, WASHINGTON, 17 April, 1843.

Dear Sir, — Yours of 14th is received. The Ordnance Board has finished its session, and the proceedings were laid before the Secretary of War for his approval some days ago. The Board passed a resolution that the Department be authorized to procure such numbers of your guns of twelve and six pounders and twelve and twenty-four pounder howitzers as it may deem the service to require, to be retained in the arsenals for future service. I learn from Colonel Bomford (who has lately returned here) that he has been spoken to on the subject; and as his opinion was adverse to the measure, I cannot yet anticipate what the decision of the Secretary will be in relation to it. When I am in possession of the papers, you shall be further advised upon the subject. I am respectfully and truly yours, etc.,

G. TALCOTT, *Lt. Col. Ordnance.*

Although these contracts were for cannon for experiment only, such was Professor Treadwell's confidence in the successful manufacture of the guns by the means devised, and that they would be adopted by the Government when their superiority to all others should be demonstrated, that on his return to Boston he set himself zealously about building the machinery, with the necessary furnaces and other works which would enable him to produce guns of large calibre with expedition and certainty.

In all the experimental work at the Mill-dam in constructing his first guns, Mr. Treadwell was alone, and wrought at his own expense, giving daily his personal attention to the manufacture of the machinery and tools. Having secured the contract, he had now associated with him Mr. Horace Gray, Dr. Jacob Bigelow, and Messrs. Rice and Thaxter, under the name of the "Steel Cannon Company."

"The result was the construction of a hydrostatic press, of fourteen-inch piston, having a power calculated at 1,000 tons, and adapting to it a variety of machinery by which the rings can be formed, and afterwards united together, with an ease and expedition, and with a perfection in form and freedom from flaw or blemish, altogether unattainable by any other means; at the same time preserving in the iron all its strength and toughness.

"A description of this elaborate machinery, and the use of it, would not be intelligible, in detail, without drawings. Nor is it necessary to my present purpose — which is to show the superiority of the cannon when made — to say more than that a number of rings or short hollow cylinders are first formed, by means of various moulds, dies, and sets connected with the powerful press before alluded to. The rings are upon their inner sides, and to about one third of their thickness, of steel; the outer portion being of iron, wound about the inner steel ring, and the whole welded together. They are then joined together, end to end, successively, by welding, thus forming a frustum of a hollow cone, the hollow being cylindrical. In giving form to the cone, in the press, its size is determined by a mould of great thickness and strength, which encloses the heated portion of the cone, while a solid mandril occupies the hollow cylinder, the force of the press being applied to sets upon its ends. The fibres of the metal are therefore closed, and the metal condensed to a degree not to be attained by the hammer. By turning and boring, this frustum of a cone is formed into the cannon, the breech being closed by a screw plug, and the trunnions fixed upon a band, which is likewise screwed upon the outside of the gun. The trunnion-band and trunnions are formed, like the cannon, by machinery moved by the hydrostatic press." *

After the machinery was got ready, Professor Treadwell had little doubt that a few months would see the cannon finished. In this he was mistaken; and in the following January he thus writes: —

To Colonel Talcott.

Cambridge, January 10, 1843.

Dear Sir, — When I left Washington in March last, I determined that I would not trouble you with any correspondence until I could inform you that the six six-pounder cannon, for which I had contracted, were completed, which I then supposed would be in a few months. Accordingly, on my return home I gave myself wholly up to making the machinery for constructing them, and others which should follow them, and from that time to this I have been so employed, *spending money* the while much beyond what I at first thought would be required. Step by step I have found some alteration to make, some error to be corrected, or some improvement to be introduced; and thus ten months have passed away. I have now, however, as I believe, brought my preparations very nearly to a close, and confidently expect to carry these six guns through the furnace in a very few weeks. I as confidently expect, moreover, that they will be most perfect pieces of ordnance, and that you will not find reason to hesitate to adopt them to the exclusion of all other kinds of cannon. But I will not anticipate what a few weeks will now bring to a sensible proof. In the mean time let me assure you that I have not forgotten, but still hold in high consideration, the open and gentlemanly manner in which you received my propositions at my several interviews with you last spring.

Daniel Treadwell.

"After about a year and a half," he says, "of most devoted and exhausting labor and a very large outlay of money, I completed the six six-pounders to my satisfaction." They were delivered to the officer appointed to receive them at the Navy Yard at Charlestown, where they were tested and accepted. They were thence sent to Fort Monroe, where they were proved in the manner now to be described.

It was suggested by the officers of Government that the most satisfactory result as to endurance and strength might be obtained by firing heavy charges, — say, to begin with, the first proof charge, and increase the resistance by additional shot, and perhaps by a corresponding augmentation of the powder charge, until the gun should be rendered unserviceable. This was considered the cheapest and most prompt mode of determining the strength of the gun.

For this purpose Captain Huger tested the Treadwell wrought-iron six-pounder No. 4, and reported as follows: "After firing 1,501 rounds, the average increase of

---

* See Appendix III. Sir Joseph Whitworth, in England, has recently used hydrostatic pressure in his heavy forging, with wonderful success.

bore was 0.002 to 0.003 inch, as shown by the measure of the accompanying table. The wear of the bore has been very slight; the vent wears very regularly and slightly, — is still serviceable, but has become angular and its greatest width is about 0.4 inch."

After this firing Colonel Talcott directed Captain Huger to try the guns of Treadwell's manufacture in the manner that the Swedish guns were tested, — viz. one new gun and the one that has stood the trial by Captain Huger of 1,501 rounds, heretofore reported, — to be fired sixty rounds, as follows: —

1st series.	20 rounds.	2 lb. powder.	1 ball.	2 wads.
2d "	20 "	3 " "	2 "	2 "
3d "	10 "	3 " "	3 "	2 "
4 "	10 "	6 " "	7 "	2 "

The following table gives the results of the testings of the guns referred to by Colonel Talcott, with which the Treadwell guns are to be compared. It will be observed that they are from Sweden, Belgium, England, and West Point. All burst at the last fire.

Extreme Proof of Six-pounder Iron Guns at Fort Monroe in 1841 *and* 1842.

Length of bore, 16 calibres; weight, 840 pounds.

Charges.				Number of Rounds Fired.					
Series.	Pounds of Powder.	Number of Balls.	Wads.	Sweden.			Gospel Oak, England.	West Point, United States.	Liege, Belgium.
				Åker.	Stafsjo.	Fin-spong.			
First,	2	1	2	20	20	20	20	20	20
Second,	3	2	1	20	20	20	18	19	20
Third,	3	3	2	7	9	10	—	—	7
Fourth,	6	7	2	—	—	2	—	—	—
				47	49	52	38	39	47

Colonel Talcott, in a letter to Mr. Treadwell on this order, says: "The Finspong guns were found to be the strongest, and reached to the fifty-second fire, when they burst, being the second fire of the fourth series. I think we shall have a good account to render you; at all events, the story will soon be told."

By the terms of the contract with the Government for the Treadwell six-pounders, it was agreed that "the weight shall not exceed 880 pounds, nor be less than 672 pounds. They shall be proved with charges required for iron guns, viz. first and second rounds, three pounds of powder, two shot, and two wads, and three rounds with two pounds of powder, one shot, and two wads; and third round, two pounds of powder, one shot, and two wads." We shall now see the tests to which the Treadwell guns were actually subjected, and that the results showed them to be far stronger than the Finspong guns with which they were to be compared.

To DANIEL TREADWELL, ESQ., *Cambridge, Mass.*

ORDNANCE OFFICE, WASHINGTON, 27 March, 1844.

Sir,— Enclosed herewith are two reports of the trial of guns No. 3 and 4, just received from Captain Huger. You will perceive that the flaws or imperfect welds gradually enlarge, but there appears to be no such thing as wearing out or enlarging the bores, and even the vents do not increase much in size with fifteen hundred discharges. I am in doubt whether to press the trials any further at this time. It seems to be almost a waste of ammunition. Let me hear your views on the subject.

I am sir, respectfully, your obedient servant,

G. TALCOTT, *Lt. Col. Ordnance.*

TO COLONEL GEORGE TALCOTT.

CAMBRIDGE, April 1, 1844.

Dear Sir, — I have received yours of March 27, with the reports of Captain Huger. You do not appear to have made up your mind upon the reports, but to me the facts shown by them are as favorable as I could have expected,—indeed, more so, as I had entertained some apprehension from what I have lately learned in making the large guns for the Navy, and as shown in a former letter to you, that many of the welds of these guns would open, as the method of making them was very defective compared with that now followed. By these reports, it seems to have done so, to a very slight extent, in a few places.

By the report on gun No. 3, you will see that the only defect, eight inches from the muzzle, was noticed before firing, and after the 1,218 fires Captain Huger says: "The edges of the defect had become somewhat worn, and the flaw a little larger. No other defects observed in the bore." It was therefore in about the same state that it was before firing.

With No. 4 there were on the interior of the bore two small cavities, one at 41.6 in., the other at 43 in. from the muzzle. These appeared slightly to increase up to 1,218 fires, when two other cavities were discovered, one 47 in. and one 13 in. from the muzzle. After 1,500 rounds, he says, "the larger flaws above noticed did not appear much increased," and the measurement gives them from .1 to .3 in. long, and .1 in. deep. Very possibly the little openings may be further enlarged by another 1,000 rounds. But it may take many thousand rounds to render the guns unserviceable, and when that shall happen, no harm can come to those about them. It seems to me, therefore, especially if we take into view the fully proved durability against wearing, that no more ought to have been expected from these first guns manufactured in this method. Indeed, all that can be said against them is that they are not perfect, and what thing was the first time ever made so? what, indeed is ever made so? Compare these with bronze guns. The proof charges borne by these would have alone ruined bronze. Compare them with cast iron. Who would willingly stand by a cast-iron gun after 1,000 rounds? and who would fear to stand by one of these? You say that "you do not know whether to press the trials any further at present, as it seems like wasting ammunition." I think it is important now, however, to go to extreme charges, and permit me therefore to suggest to you whether it would not be well to take these same guns Nos. 3 and 4, and order an increase of the charges gradually, every two rounds, until they burst or break. Probably, as the inner rings of these guns are all steel, if they burst with high charges they will make fragments. But if they open at the welds, no pieces will be thrown about.

Very respectfully, your obedient servant,

DANIEL TREADWELL.

To DANIEL TREADWELL, ESQ.

ORDNANCE OFFICE, 22 June, 1844.

Dear Sir, — The foregoing [*résumé* of experiments] has been hastily compiled from the various reports.

The measurements of the bores show no increase worth notice. The guns, as regards hardness and durability, are all that could be desired. The openings of the welds appear to be the only defects except the movements in the trunnion bands.

Yours truly,

G. TALCOTT, *Lt. Col. Ordnance.*

Extract from the Report of Benjamin Huger, Captain of Ordnance, on the Firing with high Charges of two Six-pound Wrought-iron Guns, made by Daniel Treadwell, Massachusetts. — July 12, 1844.

NOTE. — No. 4 had been previously fired 1,500 rounds with service charges, and the results reported by letter of 22d March, 1844.

20 rounds.	2 pounds of powder.	1 shot and 1 wad.
20 "	3 " "	2 " 2 "
10 "	3 " "	3 " 2 "
10 "	6 " "	7 " 2 "

After the firing the guns were carefully drawn and examined with a mirror, and found to be in good condition. The diameter of bore at each inch from the muzzle of these wrought-iron and steel guns, proved to extremity, is given in a table, and shows that the change of diameter has not exceeded $\frac{72}{1000}$ of an inch. The only disturbance in the first and second firings, those of 22d March and 16th May, was the slight turning of Nos. 2 and 4 in the trunnions, which are secured to a ring, and this screwed on to the gun. [This was subsequently remedied by means of a pin or "spline," which prevented all rotation.]

No. 3 had a defective weld or flaw at bottom of bore eight inches from muzzle; after 1,218 fires, the edges of the flaw were somewhat worn; no other defects observed in the bore. (Weight 800 pounds.) This gun, which had already withstood 1500 rounds of service charges, was tested as above, and remains entirely uninjured. Mr. Treadwell says: "No bronze six pounder gun ever made would withstand uninjured a single discharge of three pounds of powder and three shot, and, although cast-iron guns are sometimes made to resist that charge, yet the danger from fragments, in the event of bursting, must ever prevent their use with such charges with any degree of confidence."

From what precedes, it is clear that the reputation of the six-pounders as to strength and endurance was satisfactorily established. They had already been accepted by the Government after the usual proof charges. The subsequent trials were to determine their strength and endurance, as compared with other guns in the possession of the Government, and they were proved to be superior to all others.

While the making of the 32-pounders was going on, Mr. Treadwell sent the following letter to the Secretary of the Navy: —

To Hon. David Henshaw, *Secretary of the Navy.*

Cambridge, September 15, 1843.

Sir, — The first contract for 32-pounders, in March, 1842, required that they should be completed in eighteen months. I then thought that the time would be sufficient for me to perfect the machinery and methods of operation, upon which I had been employed nearly a year, and manufacture them, as well as the field-pieces which I had agreed to furnish for the Army. In this estimate of time, however, I find that I have come short, as I had but little more than completed the Army guns when it expired. . . .

It was then proposed that a new contract should be made, by which the weight of the guns should be reduced, and the time extended.

This proposition was acceded to, and a new contract made on the 3d of October, 1843, for four 32-pounders, and the time was extended to nine months from the date. The weight of the gun was reduced from 2,600 or 2,800 pounds to 1,700 or 1,900 pounds, the length of the bore 70 inches, and the size remaining the same, according to the Army Manual and the drawings of the Ordnance Bureau; to be proved by twice firing eight pounds of powder, one shot, and two wads. The guns to be delivered at the Navy Yard at Charlestown. The cost to be $1,000 for each gun.

To Wm. M. Crane, Esq., *Chief of the Bureau of Ordnance and Hydrography, U. S. A.*

Cambridge, June 10, 1844.

Sir, — The four thirty-two-pounder cannon of wrought iron and steel which I have contracted to make for the Navy are very nearly completed, and can be finished by the 3d of July according to the terms of the contract. I wish to inform you, however, that I have, since welding these guns together, made an improvement in the method of working which gives much greater certainty to the soundness of the joinings, and, although I have no apprehension that the guns now nearly finished will not stand the proof contracted for, yet I should like to furnish you with guns which may be carried to much higher charges than is provided for in the contract, that you may have at once an experimental proof of their superiority. I will therefore propose, instead of now completing these, to make four others, which, as I am now well prepared, will cause but a short delay — two or three months — beyond the time of the contract. This can be of no consequence to the service, and the advantage resulting from it may be important. The loss to me will be considerable; still, I had rather encounter it than to deliver to you guns which, although satisfying the terms of the contract, may not bear the extreme charges which may be attained upon the principles of the invention properly carried into practice. If, therefore, you will have the kindness to write to me that you assent to the extension of time, — say to October, to guard against unforeseen delays, — I will go on as above proposed, and I shall probably have the guns done in all August.

Very respectfully yours,

DANIEL TREADWELL.

These were finished in November, 1844; and although their weight was less than 1,900 pounds, the calibres being seventy inches long, one of them was proved with a succession of charges, commencing with eight pounds of powder, one shot, and two wads, and ending with twelve pounds of powder, five shot, and three wads.

They were accepted by the Government, and then, as in the case of the six-pounders, subjected to the severest test proofs in comparison with other Government ordnance.

Colonel Talcott writes to Mr. Treadwell: —

> "We have usually carried on the firing to three thousand rounds with cast-iron guns, when they would sustain that number. Your guns will doubtless be able to stand twice three thousand. I will soon propose a scale of increasing charges, similar to what has been done with other guns, that we may have elements for a fair comparison, so that when we do publish the fact he who reads can judge correctly."

As Captain Huger, who had tested the guns, was not particularly impressed with their advantages to the service, Colonel Talcott suggested to the Secretary of War "the expediency of sending him to the works on the Mill-dam to satisfy himself on the point whether any required number of guns could be made equally good, — that is, all alike, — and also to banish any doubts he may have of their strength." Orders were at once sent, and Captain Huger went to Boston, and reported to the Secretary of War as follows: —

> "From what I saw of his operations, and from the well-known mechanical skill and high scientific attainments of Professor Treadwell, I am of opinion that it is well worth the attention of the Department to give him such encouragement as will allow him fully to test his invention as applicable to the manufacture of *guns* for throwing *heavy projectiles;* and it seems to me that the point at which he should commence is the highest calibre of cast-iron guns in use, the ten-inch guns. If successful in making guns of this calibre, and overcoming the increased recoil due to their want of weight, we might progress with heavier calibres. If projectiles of such weight could be thrown with convenience and accuracy, we will have advanced a long step in the science of artillery. The effect of such projectiles must be tremendous. It is evident such guns will be particularly suited for shipping, and will be, if found practicable, far more serviceable for the navy than on land."

To Daniel Treadwell, Esq.

Ordnance Office, Washington, 26 December, 1844.

My dear Sir, — Your letter of 5th instant was duly received, and to-day also yours of 20th. The endurance of the 32-pounder Navy gun is wonderful, yet not astonishing *to me.* I called on Commodore Crane this morning, and left him the details. He had only a general statement from Commander Wadsworth, expressed his surprise, but thought no method could be devised for preventing the great recoil, and seemed to infer that the guns could never be used on shipboard. So you see the next thing is to banish his doubts on that point. I need not tell you that, the difficulty fairly overcome, I can see nothing to prevent the adoption of the guns for service on land and sea.

Respectfully and truly your obedient servant,

G. Talcott.

Mr. Treadwell, in his "Short Account of an Improved Cannon," says: —

"I have not hitherto spoken of carrying this method of making cannon to those of enormous sizes, such, for example, as shall throw shot of a thousand pounds, perhaps of many tons in weight. I can see no insuperable practical difficulty, however, to making such guns, by the method devised by me. On the contrary, I can have but little doubt that further practice will lead to the fabrication of guns of these great calibres with perfect facility. The efficiency of ordnance of this kind, especially for the defence of harbors, must be apparent at a glance.*

"On a full consideration, then, of all the facts herein related, it seems perfectly fair to conclude that cannon may be made, in the method here indicated, which shall combine in half the weight of cast-iron guns, of like calibre, a strength equal to that of the cast-iron guns.

"Taking this as true, we are next met with the difficulty of holding such light guns against the tendency of recoil. It must be evident to any one, that the action of the powder upon the shot, is accompanied with an equal action upon the breech of the gun, which produces a forcible recoil of the piece. The whole amount of the force of recoil, with guns of different weights, other things being equal, is in the inverse ratio of the weights of the guns. Now, with guns of cast-iron, of say two hundred times the weight of the shot, it is necessary, when on ship-board, to restrain or check this recoil by some connection of the gun with the side of the vessel. This connection is usually made by a very strong rope, called a *breeching*, by which the gun is suddenly, almost instantly, stopped, after it has passed backwards about four feet from the point where it was discharged. In the outset of my experiments, I was sensible, that, unless some more perfect means of governing the recoil than the common breeching was used, the full benefit of lightness derived from the strength of the material could not be obtained. It would be difficult to hold, by the common breeching, guns which should exceed but sixty or seventy times the weight of the shot, when double-shotted and fired with full charge of powder. In most of the operations in practical mechanics, the method of destroying the superfluous force of a moving body, is derived from friction. This force, if it may be called a force, has already been applied to check the recoil of cannon, by applying it to a slide upon the carriage, — a method, however, of applying the friction somewhat uncertain, and otherwise objectionable. Considering it of great

---

* The heaviest English gun is fired with 900 pounds of powder, and shot of 1,800 pounds; the heaviest French gun, with 575 pounds of powder, and shot of 2,645 pounds; and the heaviest German gun, with 615 pounds of powder, shot of 1,632 pounds. The extreme mean range of these guns is over nine and a half miles. — Major J. P. Sawyer, in Harper's Weekly, April 2, 1887.

importance, therefore, to devise some more perfect means of overcoming this difficulty, I was, after numerous experiments, led to construct an apparatus which consists essentially of a shaft passing through the carriage directly under the gun. From this shaft there is passed to the side of the ship, or any permanent object, a large, flat band, made of several ropes, bound together by a weft. Upon one end of the shaft, outside of the gun-carriage, are fixed several small plates or disks. Other stationary plates or disks are placed between these, and the whole are pressed together by a slight spring. The opposite end of the shaft bears a pulley or wheel, upon which is wound a common rope. Now when the friction-springs are open, if the last-named rope be drawn so as to turn the shaft, the flat band is wound upon it, and by that means the cannon is carried forwards to the position required for firing. Then, by the mere movement of a lever, the springs are suffered to press the plates or disks laterally against each other, and in this condition the shaft cannot revolve, so that the band shall be unwound without overcoming the friction of all the plates which rub each other. This friction may be increased to any amount, either by increasing the force of the springs, or the number of the plates or disks. I have not, perhaps, described this apparatus with sufficient minuteness to render its mode of operation very clear. I can say, however, on full experiments made with it upon a thirty-two-pounder cannon, weighing 1,900 pounds, fired with eight pounds of powder and two shot, the force of the recoil upon the band was no more than 12,000 pounds, a force which does not exceed the strength of one of the ten ropes of which the band is formed. It will be seen, moreover, that with this apparatus, as the gun is carried forward by winding the band upon the shaft, not only the common breeching is dispensed with, but also all the tackle ordinarily used for moving the gun, thus giving a clear deck to the officers and men.*

"Some objections have been made to this apparatus, on account of a supposed difficulty in managing it readily, by the seamen or artillerists. The same objection may be made to the common gun-lock, because it is more complicate than a match. The same objection was most likely made by the ancient spearmen against the bow and arrow; and by the latter, in turn, against the whole apparatus for using gunpowder. It has always been made against new machinery, and has always yielded to the skill acquired by a little time and practice. But, conceding for a moment the possibility that this apparatus cannot be advantageously used, we may yet resort to the common breeching, and obtain a great part of the advantages of these wrought-iron cannon. For although in this case the force of the recoil may not permit us to reduce the weight to the extent that it might be, if the motion of the gun were restrained by friction, it may still be so reduced as to give advantages, both on sea and land, unattainable by any other means."

The construction of the apparatus will be understood from the accompanying figures. Fig. 1 shows an elevation of the carriage, with the parts added to the same. Fig. 2 shows a horizontal section. Fig. 3 is a horizontal section through the winding shaft, to be described. An inspection of the figures will show a carriage of the common description, mounted on four wheels. It will be seen that the

---

* This method of controlling the recoil was early adopted in England. Colonel E. Maitland of the Royal Artillery says: "The development which has taken place of late years in the power of artillery has necessitated corresponding changes in gun-carriages. Extra means of checking recoil became necessary as the guns grew; compressors, or friction plates, were introduced, and are now [1880] only partially superseded by the hydraulic buffer." In 1873 the editor of this Memoir saw, at the Woolwich Arsenal, field-pieces fitted with friction-plates beneath the guns for this purpose. Similar methods at the same time were also in use for the heavy cannon at Tilbury fort.

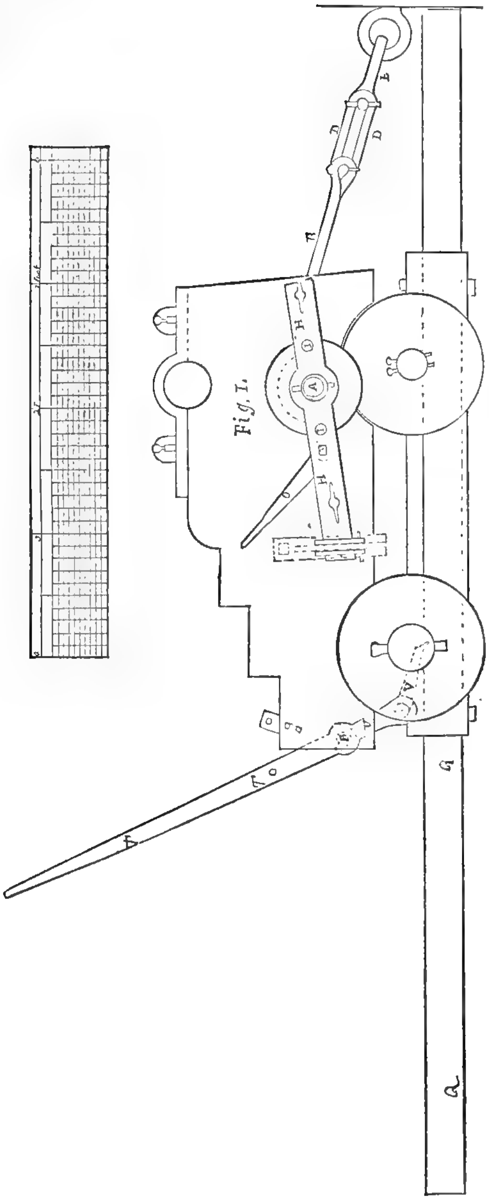


Fig. 1.

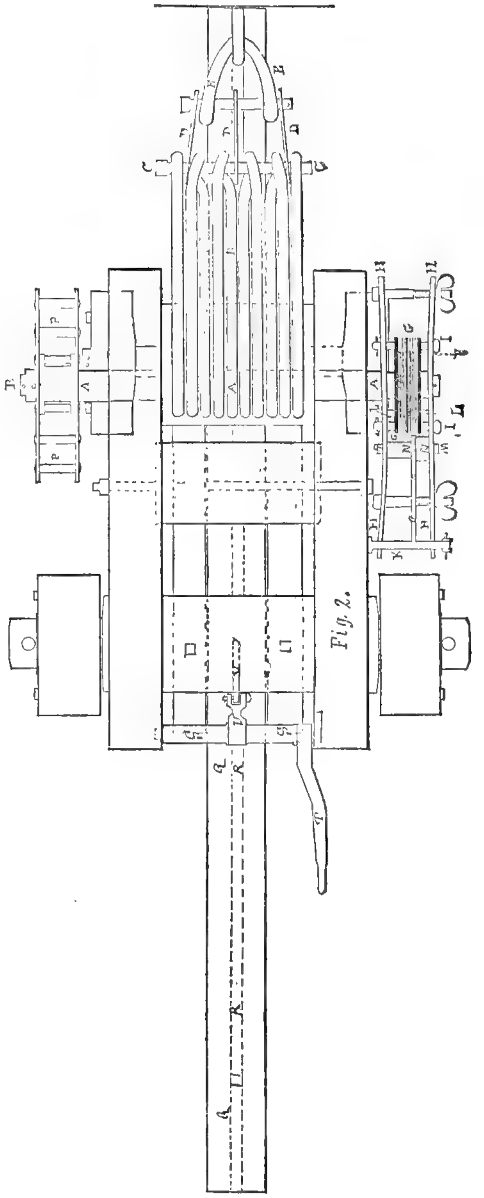


Fig. 2.

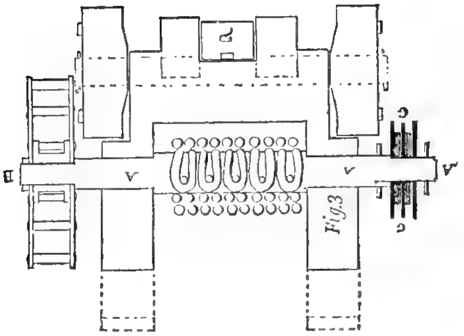


Fig. 3

forward wheels are placed nearer each other than the hind wheels, and to permit this arrangement the sides of the carriage are cut away upon the outside, as shown in Fig. 3. Through the sides of the carriage directly under the gun is passed an iron shaft, A A; upon this shaft is arranged a flat band, B B, made of rope bound together by a weft of small line (the weft not shown in the drawing). The section (Fig. 3) shows the band as cut through when wound upon the shaft. The band is of one piece of rope doubled to make eight or ten strands, and is secured to the shaft A by passing the doublings through holes in it. Iron pins are passed through each doubling, which prevent its being drawn from the shaft. Through the doublings at the other end of the band an iron bolt is passed, C C. This bolt likewise passes through three links, D D D. These links are connected by another bolt to the shackle, E E, which is fastened to an eye-bolt in the side of the ship. On one end of the shaft are the friction plates, F, which are secured by projections on them to grooves in the shaft, so that they must turn with it, but can slide on it to or from each other. Between each two of the plates is another plate, G, Figs. 2 and 3. H H are two springs, one on each side of the plates. These and the plates G are fastened by a bolt, K, to the carriage, so that they cannot turn on it, but the shaft A moves freely in holes made through them. The springs are drawn together by screw-bolts. The object of the apparatus is to make a powerful friction to resist the turning of the shaft A and the unwinding of the band B, and consequently to restrain the recoil of the gun and carriage when fired. The operation of this is as follows. Let the gun and carriage be carried forward so that the band B B shall be wound firmly upon the shaft A A, one end of the band being fixed to the shaft, as before described, and the other end to the eye-bolt; then let the springs H H be drawn together by the screw-bolts so that the sides of the plates or disks F F and G G, Figs. 2 and 3, are pressed against each other. Now, when the gun is discharged, the carriage cannot move backward without unwinding the band B B, by which the shaft A A must be turned round. This must cause the plates or disks F F to revolve; but as the plates G G are connected by the bolts I I with the springs, which are prevented from turning by the stud K, the plates F F in revolving must rub their sides against the sides of the plates G G, and this friction must resist the turning of the shaft A A, the unwinding of the band B B, and, consequently, the recoil of the gun and carriage. The resistance may be increased by increasing the number of plates and the pressure of the springs. To relieve the friction and permit the shaft A A to turn, the lever O, Figs. 1 and 2, has on its lower end a wedge-shaped block, which, when forced between the springs, presses them apart. On the other end of the shaft A A is fixed a wheel, P P; to this is fastened a rope, which is wound up when the gun recoils; by pulling upon this rope the gun can be drawn forward for firing. Q Q is a guide tongue, fastened by one end to the side of the ship under the eye-bolt, and passing beneath the carriage in grooves in the axle-trees, and may be used to train the gun.

Mr. Treadwell laid his gun-carriage before the Naval Department and explained its advantages. To gain further information as to the efficiency of the recoil apparatus, Commander Wadsworth received orders to proceed to Boston and there examine it in practice. He reported as follows: —

COMMANDER ALEX. S. WADSWORTH TO COMMODORE W. M. CRANE.

SANDY HOOK, August 15, 1845.

Sir, — I have the honor to inform you that I have examined and tested the gun-carriages of Mr. Treadwell at Boston, so far as it can well be done on shore. The principle of checking the recoil by mutual friction-plates appears to be good and sufficient with the service charge of powder; but its application to ship gun-carriages, as in the present instance, would I think present many inconveniences, and render them unsuitable. This could be more properly tried on a ship at sea. Only one of these carriages was in readiness for trial, on which Mr. Treadwell's gun was mounted, and fired fourteen times, generally with the service charge of four pounds of powder. The carriage runs on trucks; the breeching is formed of ten parts of a three-inch rope matted together so as to present a broad flat surface the width of the gun. One end of it is attached to a revolving axle, which passes through the cheeks of the carriage under the gun, and the other end secured to the port. It is wound up on the axle when the gun is run out, and unwound when it recoils. On one end of the revolving axle extending through the cheek is a number of metal friction-plates — fifteen or twenty — eight or ten inches in diameter, acted upon by a spring which is worked by a hand-screw. This checks the recoil. The whole projects about nine inches from the carriage. To the other end of the axle is attached an iron wheel about twelve or fourteen inches in diameter, used with a single whip through a block in the side of the ship for running out the gun. This also projects about nine inches. Underneath the carriage, and lying on the deck with one end bolted to the water-ways, is a tongue of timber about six inches square and eight or nine feet long, having a rack on it and a pall and lever attached to the inner end of the carriage when training. When firing the gun with four pounds of powder, the recoil seemed to be checked sufficiently, and controlled by the friction-plates, and prevented from running out again by the rack and pall. . . .

TO MR. TREADWELL.

BUREAU OF ORDNANCE, 8 September, 1845.

Sir, — The gun-carriages constructed under your directions for the wrought-iron guns, I apprehend, will not be found to answer in actual service. The tongue under the carriage will be found very inconvenient on board ship, — taking up room and obstructing the passage on deck, and when the gun is trained, I understand, the strain is brought on a single part of the breeching; these are serious, if not fatal objections. I enclose Commander Wadsworth's report on the gun-carriage. Unless the objections therein stated can be overcome, I do not feel justified in furnishing a part of the armament of our ships with these gun-carriages.

I am, very respectfully, your obedient servant,

W. M. Crane.

To Commodore Crane.

Cambridge, September 10, 1845.

Sir, — I have received your letter of the 8th enclosing Commander Wadsworth's report of the trial of my gun-carriage, and beg leave to lay before you some observations on the objections made to the carriage by Commander Wadsworth and embodied in your letter. These are, first, to the tongue under the carriage for directing it to the middle of the port. Now, this tongue does not extend farther from the side of the ship than through the space over which the cannon recoils, and it may be shortened at least a foot more. It extends to a less distance than the cheek pieces or slides upon which the carriages lately made, I think, for the Marion extend, and does not take up half so much room upon the deck. Moreover, it is intended to be unshipped and laid aside when the gun is not in use. If, however, it is considered objectionable, it may be taken entirely away, and the carriage can be left to work without it in precisely the same manner that a common carriage works, without diminishing in the least degree the effect of the apparatus for preventing the recoil, as it has nothing whatever to do with holding the gun against the recoil, but merely directs it to the middle of the port.

For the second objection enumerated by you from Commander Wadsworth's report, that the strain when the gun is trained forward or aft is brought upon a single part of the three-inch rope of which the band is formed, I have to say that, but for a severe illness which prevented me from being present at the experiments and explaining to Commander Wadsworth the method by which I intend to fix the band to the side of the ship, this objection would not, I am sure, have been made, as I should have shown that it is intended to fix the band on shipboard to an eye-bolt upon which it can swivel in all directions; whereas in the experiments made before Commander Wadsworth it was attached to a dynamometer for the purpose of showing the exact force of the recoil. By this mode of fixture, the strain under the conditions stated in the report becomes unequal upon the different parts of the band. But when fixed, as intended on shipboard, to an eye-bolt, the objection will be entirely obviated, and the strain must under all circumstances be equally diffused upon the band. I hope that this explanation will be thought by you sufficient to warrant the conclusion that neither of the principal objections contained in your letter can be taken to remain against the carriage.

Permit me further to observe concerning Commander Wadsworth's report, that, while he enumerates the liability of the friction-plates to be broken, and likewise that these and the side-wheel will be likely to catch the rigging in working the ship, he makes no mention whatever of the great amount of tackle necessary to the old carriage, but not required in this. Indeed, I cannot but think that, on reflection, he will be sensible that the deck of the ship furnished with these carriages will be much less encumbered with ropes and blocks, over which the men must pass, than the deck which bears the common apparatus as now used. I certainly thought that this fact, and the less number of men required to work the carriage from the ease with which it is moved, ought to be taken as circumstances much in its favor, and I cannot but lament that they have escaped Commander Wadsworth in his report.

I trust, sir, you will not suffer the experiments to rest here, but direct a trial on shipboard, which will be the only true test; and, as there can be no dispute as to the sufficiency of the friction as here made to destroy the force of the recoil, however heavy the charges or however light the guns, I feel warranted in claiming for it your early attention.

Very respectfully yours,
DANIEL TREADWELL.

This letter appears to have had no effect in removing Commodore Crane's objections, and, as a last resort, an appeal was made to the Hon. George Bancroft, then Secretary of the Navy.

TO THE HON. GEORGE BANCROFT.

CAMBRIDGE, September 15, 1845.

Dear Sir, — I enclose to you herewith a letter addressed to you as Secretary of the Navy on my improvement in cannon, in which I have stated at some length what may be expected from adopting it. I have received from Commodore Crane a copy of a report made to him by Commander Wadsworth, in some degree condemning my gun-carriage, and have written to Commodore Crane a reply to his letter and the report. I wish very much that you would take the trouble to read these letters and the report, of which it is not necessary for me to send you copies, as they are all in Commodore Crane's office. The truth is, that the old officers, with all respect be it spoken, are so entirely *conservative* that no improvement can be introduced with their good-will, and it must rest with you principally to give this improvement to the Navy or to let it die.* I do not see that anything more can be done by me in the getting up works for making these cannon without Government help, as I have already spent so much time, health, and money upon it that I have come to the end of my tether in the work if it be not taken hold of in earnest by Government. Whether it deserves this or not I leave to your judgment after reading the accompanying letter, in which I have stated the case as fairly as I could have done it if I had no interest in it. Should I desire to print the account of the improvement in the form in which it is addressed to you, I presume you can have no objection.

Very respectfully, your obedient servant,
D. TREADWELL.

---

* Mr. Treadwell was not alone in his views of the old Commodore. Mr. Howard, from the Joint Committee on Ordnance, submitted, February 15, 1869, a report to the United States Senate, in which, commenting on the want of interest of the Chief of Ordnance of the Navy, is the following: "The difficulty seems to be twofold. First, the ordnance officers, knowing their position secure to them for life, have not felt the incentive to exertion and improvement which stimulates men not in the Government employ, and they have become attached to routine and to the traditions of their corps, jealous of innovation and new ideas, and slow to adopt improvements. In the second place, these officers, educated to a specialty and proud of their positions, come to look upon themselves as possessing all the knowledge extant upon the subject of ordnance, and regard citizen inventors and mechanics who offer improvements in arms as ignorant and designing persons and pretentious innovators, who have no claim to consideration. Another difficulty that has retarded progress in the science of ordnance has been the fact that prominent officers have been inventors of arms, and have possessed sufficient influence to secure the adoption and the retention in service of their inventions, frequently without due regard to their merit, and to the prejudice of other and better devices brought forward by citizens or developed in other countries." The committee recommend "that every encouragement should be given to inventors, and a full and fair trial accorded to all devices offered to the Government that promise a solution of the ordnance problem."

Although the gun-carriage and recoil apparatus were not adopted by our Ordnance Bureau, subsequently, as appears by the following letter, its value was appreciated by some of the more intelligent officers.

To PROFESSOR DANIEL TREADWELL, *Cambridge, Mass.*

NAVAL OBSERVATORY, WASHINGTON, January 27, 1869.

Dear Sir, — I am getting together some notes on the subject of gun-carriages, and, if I do not mistake, I saw on board the U. S. Revenue Steamer McLane, in the Gulf, during the Mexican War, a mode of compression involving the same principles made use of by Ericsson in his latest plan of the Dunderberg. The McLane's carriages, I understood, were of your invention.

If so, will you be so good as to furnish me with a sketch of the arrangement; the notes will be published for the use of the Naval Academy, and I desire to give credit to the several inventors, among whom you are one of the earliest and most distinguished.

Very respectfully,
WILLIAM N. JEFFERS, *Commander U. S. Navy.*

TO WILLIAM N. JEFFERS, ESQ., *Commander in the U. S. Navy, Naval Observatory, Washington.*

CAMBRIDGE, January 30, 1869.

Dear Sir, — In answer to your letter of the 27th instant, I have to say that I have no knowledge of the gun-carriages used on the U. S. Revenue Steamer McLane. But I herewith enclose to you a pamphlet published by me in the year 1845, entitled "A Short Account of an Improved Cannon." On pp. 14, 15, and 16 of this pamphlet will be found a general description of a method, and apparatus, for restraining the recoil of ordnance, invented by me in 1842. Two of my wrought-iron 32-pounders were mounted upon carriages, constructed by me, with this apparatus, and are now *probably* in the Ordnance Department of the Navy Yard in Charlestown. It was fully proved, by a long course of experiments, that this method of controlling the recoil is entirely efficient.

So far as I know, the method of increasing the resistance of the friction of a given load, or pressure, by an increase of the *number* of the plates, or surfaces, upon which the load acts, was first applied to a useful purpose in this apparatus. Nor am I aware that the fact that the resistance of friction could be so increased, or that the law of the increase of the resistance follows the direct arithmetical increase of the number of the plates or surfaces upon which the load or pressure acts, had been pointed out by any experimenter or writer before it was recognized by me.

No patent has been taken in this country for this method of governing the recoil of guns, but a patent was taken for it, on my account, in England, in the year 1845. This English patent was taken by and in the name of Thomas Aspinwall, then U. S. Consul in London. I have no copy of the English patent, but it can undoubtedly be found at full length in the "Specifications of Patent Inventions" published by the English government. A copy of this great publication is or ought to be found in the Congressional Library.

Very respectfully, your servant,
DANIEL TREADWELL.

The English patent was enrolled December 23, 1845, "For improvements in ordnance carriages; comprising apparatus for governing the recoil, and likewise for moving the piece of ordnance backwards and forwards." No. 10728, English Printed Specifications of Patents.

The pamphlet referred to by Mr. Treadwell is that addressed to Secretary Bancroft, and afterwards in the main printed as the "Short Account of an Improved Cannon," from which the preceding extracts have been taken. Neither the Account nor the letter addressed to the Secretary personally, calling his attention to the very great importance of the subject, appears to have produced any favorable effect upon the Department. Nevertheless, Mr. Treadwell was so thoroughly convinced of the superiority of his cannon over any before tested, that he was quite sure, on business principles, that the Government would adopt them, and he therefore continued manufacturing them on his own account.

The labors he had undergone during the four years devoted to this work and to his other duties as agent of the Spinning Company had become too much for a constitution never strong, and obliged him to lay down a part of his burden. The professorship in Harvard University was that least connected with the pecuniary interests of others, and he therefore sent to the President the following letter of resignation.

TO HON. JOSIAH QUINCY, *President of Harvard University.*

CAMBRIDGE, May 12, 1845.

Sir, — The continuance of infirm health, together with the pressure of engagements which require much of my time and attention, render it impossible for me to deliver my course of lectures on the Application of Science to the Arts to the students of the University at the present term. I must, therefore, beg leave to present to you my resignation of the Rumford Professorship, which I have had the honor to hold for the past ten years. Permit me, sir, at the same time, to ask you to accept my most respectful acknowledgments for the constant attention and kindness which you, and every menber of the College government with whom I have had intercourse, have ever extended to me.

With great respect, your most obedient servant,
DANIEL TREADWELL.

TO PROFESSOR TREADWELL.

CAMBRIDGE, June 14, 1845.

Sir, — I have the honor herewith to transmit an official copy of the vote, passed by the President and Fellows of Harvard College, on receiving your letter announcing your resignation of the Rumford Professorship.

Be assured, Sir, that I feel personally all the regret expressed by that Board at an event which has deprived the University of your highly valued talents and services; and that our official connection, and the mutual and uninterrupted kindness and respect with which it has been sustained through a series of years, will constitute one of the most grateful and cherished reminiscences of

Very truly, your friend and obedient servant,

JOSIAH QUINCY.

At a special meeting of the President and Fellows of Harvard College in Boston, June 7, 1845, the President laid before the Board the letter from Professor Treadwell, resigning his office of Rumford Professor. Whereupon, —

Voted, That the President and Fellows receive with great regret the letter of Professor Treadwell, announcing his resignation of the Rumford Professorship in Harvard University, and above all that his infirm state of health should be one of the causes of thus depriving the institution of his valuable services.

The President and Fellows recognize on this occasion the ability and fidelity with which Mr. Treadwell has fulfilled the duties of his office, and all the satisfaction and benefit the institution has derived from his services; and in accepting his resignation reciprocate towards him their respectful acknowledgments for the kindness which always characterized his intercourse with them, and their best wishes for the restoration and permanent establishment of his health.

A true copy of record. Attest,

JAMES WALKER, *Secretary of the Corporation.*

As already stated, a joint stock company was formed immediately after making the contracts with the United States Government for the thirty-two pounders, and the work at the Mill-dam was still carried on by that company. A new and larger company was formed under the name of the "Steel Cannon Company," which was incorporated by an Act of the Legislature of Massachusetts, dated February 26, 1845, "For the purpose of manufacturing cannon and any machinery that may be used for the manufacture thereof in the Town of Brighton." This company included the gentlemen already named as of the first company, and in addition Messrs. P. T. Jackson, J. A. Lowell, George W. Lyman, and George Gardner. To the new company was transferred the property of the old one, amounting to $50,000, and the capital was raised to $96,000, of which Mr. Treadwell contributed a much larger proportion than any of the others. The inducement to form this company was, first, the demonstrated superiority of the guns, and, secondly, an intimation from Washington that they would be adopted, and Colonel Talcott's letter of the 17th of April, 1844, that the Board of Ordnance had already recommended to the Secretary of War the manufacture of the Treadwell guns of various sizes.

Land was bought in Brighton, conveniently situated for the transportation of materials, by the side of the Boston and Albany Railroad, and the requisite buildings erected.

The making of the thirty-two pounders seems to have been attended with some unexpected difficulties, and the appearance of cracks in some of the guns alarmed Mr. Treadwell. He immediately communicated the fact to those associated with him, and charged himself with the expenses of the work going on at the Mill-dam to the amount of $2,000, if it should not prove successful. He went with Mr. Francis C. Lowell to Washington, and laid the matter before Colonel Talcott, who had been urging the adoption of the guns by the Navy Department. Colonel Talcott considered the accident as most unpleasant, but believed it could be overcome. The work went on, until the cannon, twenty-two in all, were completed.*

In 1845 M. Buggraff, an agent of the French Government, visited Mr. Treadwell's works at the Mill-dam, investigated his method of manufacture, and made himself acquainted with the results of the proving of the guns at Washington. After this visit he received the following letter from Mr. Treadwell, offering one of the 32-pounders to the King of the French.

To Mr. Buggraff, *Agent of French Government.*

Cambridge, November, 1845.

Sir, — I have placed in Boston, subject to your order, one cannon, with the request that you will forward it to the proper officer of the government of His Majesty the King of the French, to whom I wish it to be presented. This gun, the calibre being of the size of an English 32-pounder, is made of wrought iron after a method invented and reduced to practice by me, and a short account of which is contained in the pamphlet which you will receive with this. I have already furnished to you an account of the proof to which several field guns, made by me, have been subjected by the Ordnance officers of the United States. The gun now forwarded was manufactured by the same process, but is less perfect than the field guns, in being made all of iron, instead of having its calibre faced with steel as used in the field guns. The reason of this difference, and the deficiency of hardness which results from it, is noticed in the pamphlet, page 13, and in consequence of it a lodgement may be produced if soft wads are used with high charges and several shot. With the exception of the particular above alluded to, this gun is, I believe, every way perfect; it has been proved with twelve pounds of powder, two shot, and

---

* Similar difficulties have since been met with elsewhere. At the Russian government foundry it often happens that cracks are found in the cylinders of which the bodies of the guns are formed, after being submitted to the hammers during the process of welding. "Some of these are inconsiderable, not deep, and have no influence on the quality of the metal, or the resistance of the cannon itself. Sometimes, on the contrary, these fissures are of a sufficiently great extent to cause the rejection of the piece. Minute observations have shown, that of these non-malleable pieces there have been some of which the casting, forging, and reheating have taken place under exactly the same conditions as with other cylinders that have proved of the best quality. Chemical analysis has not been able to assign an explanation for these fissures; even at the point where they have occurred. . . . Unfortunately, this fact, than which there can be none more interesting, awaits, like a great many others respecting the production of cannon steel, a satisfactory explanation, which as yet the engineers and chemists of the works have not been able to furnish." — Notes on the Construction of Ordnance, No. 21, p. 16. "Fabrication of Cannon in Russia, by Lieut. Michel Levitzky, Russian Navy." Washington, May 14, 1883.

two wads. I commend it, however, to the *ingénieurs* and scientific officers of France, to subject it to such proof as they may deem necessary to enable them to judge of its qualities compared with other cannon.

This gun was sent by M. Buggraff to France in November, and was deposited in the Museum of Artillery at Vincennes. In 1847 it was tested by a French commission, the report of which will be given further on.

The "Short Account" was sent to scientific and practical men, and to many of the naval and military officers, and to the Departments at Washington, in the hope of convincing them of the value of the invention. The following letters from Colonel Talcott indicate his confidence in the invention, and his endeavor to convince others of its value to the country.

To DANIEL TREADWELL, ESQ.

ORDNANCE OFFICE, 3 October, 1845.

Dear Sir, — It appears scarcely possible that I have had your letter of 12 August for six weeks; but the date assures me of the fact. "I have been under the weather" until lately, and hardly know what has been done and what omitted. I had an interview with Crane and Wadsworth some time after the receipt of that letter, and came to the conclusion that the gun-carriage had no chance. I sought an interview with the Secretary, and intended to read him a portion of the letter, but did not succeed in seeing him. I was pleased to learn you had sent him an *exposé* of the whole business. Crane furnished me an opportunity of reading it, and, by his desire, I gave a written opinion in favor of your views. The Secretary went to Norfolk that evening, and I have seen nothing of him or Crane since that day. Crane has sent me recently Wadsworth's statements. He is averse to all your plans, and I think Crane will back him, but with hesitation. There is a vague rumor abroad that B—— will soon leave his present office, but I do not credit it. The remark in yours of 29th, that the Navy do not think an increase of calibre advisable, because, if made, the British will do the same thing, and bring all equal gain (!!!), I have heard from several officers, and have not failed to show its fallacy. Mr. Bancroft has not been much abroad lately, — or, if so, I have not seen him as formerly. I have no doubt you will hear from him on the subject of your memoir shortly, at any rate. I will see Crane soon, and give you the result of my interview.

Respectfully and truly, your obedient servant,

G. TALCOTT.

To DANIEL TREADWELL, ESQ.

ORDNANCE OFFICE, 29 December, 1845.

My dear Sir, — Your letter of 24th instant was received this morning. The pamphlets came on Saturday. I have put one into the hands of a member of the Committee of the House of Representatives on Naval Affairs, and a man who is disposed to improve the Navy. I have seen the Secretary of the Navy only once for a long time past (I believe nearly three months), about two weeks since, when he spoke of your gun, and the want of confidence in it by Commodore Crane, said you had urged a trial, and I responded, "Try it, sir, the old officers cannot object to a trial." I still think him inclined to prosecute the matter, and shall omit no opportunity to strengthen his good feeling.

I have no hesitation in approving all you put forth in favor of the gun. The argument used by Navy officers, that, "if we carry such guns, the British will also have them, and then we shall possess no advantage," is well set forth by you. I have added, "But suppose the British adopt them and we do not?" All that is necessary to put the matter beyond all question, I consider to be a full trial, upon either your carriage or some other, and the best carriage that I have seen is now in Crane's office. It has been gotten up by Mr. Alger. The only objection to it arises from the too free use of *cast iron*. Wood and wrought iron may be substituted, making it all that can be desired. Do not infer from my silence that I have been indifferent to your success. I could do nothing but talk on the subject, and this I have done to every one that has come in my way, and I shall still say, as I have done, that your guns can be neither burst nor worn out, and refer to the facts of the various trials.

I am just now pressed with business, but I beg you to write me as often as you please, and I trust you will excuse present haste.

Yours respectfully and truly,
G. TALCOTT, *Lt. Col. Ordnance.*

Mexico declared war against the United States in June, 1845, and the "Short Account," which had been circulated in Washington, seems to have produced some effect upon members of Congress, especially upon Mr. Thomas Butler King of the Committee on Naval Affairs and some of the younger naval officers, — among them, Lieutenant (afterwards Admiral) Charles Henry Davis.

Mr. Treadwell, encouraged by this and especially by the efforts of Colonel George Talcott, went to Washington, in February, 1846. Judging, however, from the following letters, his success seems not to have been great in promoting the interests of his cannon.

WASHINGTON, February 4, 1846.

Dear A., — I saw Colonel Talcott this morning, and found him firm as ever, very glad to see me, and ready to do anything for me, even taking shame to himself that he has not succeeded in procuring the favorable action of Government, and not yet despairing of it. Were he a bribed agent, he could do no more than he does from a sense of right, or a desire to be of service to me.

From his office I went over to Commodore Crane, where I found all the reverse. The Commodore and his officers are determined, as I supposed they were, against me, and all talk, I saw, would be useless.

To-morrow I shall see some of the committees or members of committees.

Yours,
D. TREADWELL.

Discouraged so far as the Navy was concerned, he returned to Cambridge, and thence writes to Lieutenant Davis and Colonel Talcott as follows: —

To Lieutenant Charles Henry Davis, U. S. N.

Cambridge, March 30, 1846.

Dear Sir, — I am exceedingly obliged to you for your attention in the matter of my cannon. I have delayed answering your last letter from an expectation of receiving from Colonel Talcott an account of some definite action by the Ordnance Board of the War Office, but I am yet held in waiting for it. I have come to the conclusion that any further attempt, for the present, to obtain the favor of the officers of the Navy Ordnance will be useless, and I shall therefore give it over. I do this the more willingly, as I think that the Army Ordnance will soon do all that I can reasonably expect in the way of ordering a contract for field guns. As the matter stands, therefore, any action of Mr. King, or other members of committees, would not, as I think, be useful to me, while it would be troublesome to themselves. Still, I am much obliged to him for his readiness to attempt an advance.

Renewing the expression of my thanks for your attention, I assure you that I am most truly your obedient servant,

Daniel Treadwell.

To Colonel George Talcott.

Cambridge, April 14, 1846.

Dear Sir, — I determined when I left Washington that I would not give you the trouble of a letter again until I should have something definite from you of the result of the meeting of your Board of Ordnance. My impatience, however, under my present state of doubt and suspense, has overcome my resolutions so far as to make me ask of you whether you have yet had the contemplated meeting of your Board. You saw that I despaired of the Navy when in Washington. Nothing has occurred to alter that feeling, and if your Department do no more for me, I must rest with no more done. . . .

Daniel Treadwell.

Mr. T. B. King, May 20, 1846, reported from the Committee on Naval Affairs a bill for the construction of twelve iron war steamers, and one iron frigate. They were to be of not less than twelve hundred nor exceeding sixteen hundred tons burden, with a speed of at least fifteen miles an hour in ocean navigation in ordinary weather, and capable of carrying an armament of at least six of Treadwell's wrought-iron guns of not less than twelve-inch calibre, and from two to four smaller guns of the same manufacture. The following is an extract from their report.*

"The committee have recommended that the armament of these ships shall consist of Treadwell's wrought-iron guns, of at least twelve-inch calibre, and it is proper that something should be presented in support of the recommendation. For this purpose the committee submit an ample extract from Mr. Treadwell's pamphlet, which will be found at the close of this report, and will, it is believed, fully justify their views. It is perhaps true that some prejudice exists against the employment of wrought-iron guns; but it is not doubted that Mr. Treadwell's improvements, and a full and thorough examination of the subject, will dispel all

---

* See House Doc. No. 681, 29th Congress, 1st Session.

doubts, and lead to their general use in our naval armaments; and that the important fact will be disclosed, that, by the adoption of these wrought-iron guns, the destructive power of our ships of war may be at once doubled, and that frigates and perhaps sloops of war will be able to contend successfully with line-of-battle ships as at present armed."

The bill seems to have been lost, as there is no further mention of it.

The war with Mexico was still going on, and the demand for lighter and more efficient field artillery seems to have increased; and a year after the introduction of Mr. King's bill, and three years after the Bureau of Ordnance had recommended a supply of Mr. Treadwell's guns to be placed in the arsenals for future service, the Secretary of War approved the recommendation of the Bureau, and Mr. Treadwell's constant friend, Colonel Talcott, thus writes: —

To Daniel Treadwell, Esq., *Cambridge, Mass.*

Ordnance Office, 24 April, 1847.

My dear Sir, — The Secretary of War has at last approved the proceedings of the Ordnance Board, held in March, 1843, and amongst other projects, you know, was one for procuring a supply of your cannon. The opposition then and now existing to the measure, I suppose, may be found in your neighborhood, where experiments are in progress to furnish field guns of cast iron that shall meet all the wants of the service. My idea was to substitute 12-pounder guns and 24-pounder howitzers for the 6-pounder and 12-pounder howitzers, without a considerable increase of weight, certainly not over fifty per cent.

How do you stand disposed in relation to this matter, after so long a delay? I suppose we ought to try a couple of each before going largely into the matter, but such a course would involve too much expense, perhaps. I am not aware how you proposed to make chambers for the howitzers. They seem to be necessary, on account of the small charge used, but I am not quite sure that they are indispensable. Let me hear from you when convenient.

Respectfully and truly, I am, dear sir, yours, etc.,

G. Talcott, *Lt. Col. Ordnance.*

To Colonel George Talcott.

Dear Sir, — Your favor of April 24, 1847, was received in due course of mail, but I have been unable to make up my mind for a definite answer to it until now, as it required much time for consideration both by myself and by the gentlemen who have been engaged with me in the cannon manufacture. In November, 1845, the Navy having decided to give no encouragement to me to proceed with guns for that service, and it being uncertain what would be done by your Department, I was obliged to stop the works then in progress and discharge all the workmen who had been employed by me. The old machine-shop in which I had finished the cannon then made, and in which I was a tenant at will, was likewise given up, and is now occupied by another person. You perceive therefore that to recommence the manufacture I must provide a new machine-shop with lathes, boring engines, and all the necessary finishing tools, as well as collect again workmen in every department of the art. The question then is whether, under this condition, the manufacture of guns for the field service of the United States only will be sufficient to warrant the necessary expenditure and labor required for recommencing operations. My conclusion is, that it is very doubtful whether it can prove so, even if I were certain that I should have the manufacture of all the guns required for the field service; but when I take into consideration the caprices by which I may hereafter be put out of employment,— when I consider that, with your powerful personal influence and favorable opinion and that of your Ordnance Board, more than a year has passed before the Secretary of War has ratified your recomendations, — I think, and I believe that you will agree with me, that it would be most unwise to incur the great expense of preparation for work that cannot be of assured permanency. We have therefore concluded not to recommence the manufacture under the present aspect, without some prospect should come from abroad; and in this connection permit me to relate to you that I have lately had advices direct from France that the 32-pounder sent there has not yet been proved, notwithstanding the account which was given in the American papers in June, 1846, that it had been tested at Vincennes. My account is from a general in the ordnance service, who was applied to by letter from the French Consul here, and who writes under date of February that it had not then been proved, but that it was intended to try it in a short time. My friends engaged with me here are desirous that I should go out to France and see for myself the upshot of the matter there, and this course I shall probably, almost certainly, pursue. Should the proof in France be favorable, it may end in that encouragement that shall induce me to take up the manufacture here; but should the French officers think that "cast iron is as good as wrought," or that the material now used for guns is "good enough," it will be the end there, and probably here also.

I pray you again to accept my most sincere acknowledgments for your constant attention to me, and for the efforts made by you in favor of these cannon. As I have been made bold by your many kindnesses, I will now venture to ask if you are acquainted with any officers in the French service to whom you would feel free to give me an introduction, as your letters would, I know, be of great value to me in France.

With great respect,

Daniel Treadwell.

Following out the plan proposed in the foregoing letter to Colonel Talcott, Mr. and Mrs. Treadwell sailed for England in August, and arrived at London in the latter part of the month. While in London he made no attempt to view any of the military establishments, but occupied himself in renewing his intercourse with his old friends, the Vaughans, Dr. Boott, Mr. Bates, and others, and going over again with Mrs. Treadwell and Mrs. William Parsons what had interested him in his former visits.

To Dr. John Ware.

London, No. 135 Regent Street, August 31, 1847.

Dear Doctor, — Your letter of July 27th reached me on my arrival here three days ago, and I am greatly indebted to you for your considerate kindness in writing so early to me. . . . From Liverpool we went to Kendall, then to Bowness, Ambleside, Keswick, and Penrith, taking in all four or five days. [Note. — M. H. and M. P., two of our fellow passengers whom we met in our route, told us that in passing Rydal Mount they sent a note to Wordsworth begging his permission to pay their respects to him. He returned a polite answer, and they say he was much pleased with their attention and homage. Wordsworth asked them about American historians, they mentioned amongst others Mr. Prescott; Wordsworth said he had heard of him, and had some thoughts of getting his books to look over them. Shall we say that Wordsworth is ignorant, or Prescott obscure?] From Penrith to Carlisle and Glasgow, then to Edinburgh, Melrose, Durham, and York. This with days at other places consumed four weeks from Liverpool to London. The journey had all the externals to make it delightful; but that word I find does not match well with the color of fifty-five (almost six), and I must be content to say all went well.

An idea got possession of me at York, that that place is the point where the two coexisting worlds most completely meet and mingle with each other. I do not mean the material and spiritual worlds, as you Swedenborgians have it, but the old world and the new world. We go to that old cathedral, with its leaning and crumbling magnificence, and are shown by a tottering old verger into an old carved oak seat. An old canon gets up and reads about "Shadrach, Meshach, and Abednego" to an audience of half a dozen old men and women. All seems like the last venerable remnant of an age which has gone, — the shadow of a body which is no longer seen. We pass from the minster to the railway station (only half a mile), and all is life and exertion, — the strength of the young world in its prime, bent upon advancement, progress, and reform, and regardless of its venerable father, repeating his prayers almost within ear-shot of the scene of its labors. All this seemed to me as the nearest possible approach to bringing Rome and Florence to the side of New York and Boston.

We have hardly begun our London sight-seeings, but I have been about enough to see that London has advanced greatly since I was here twelve years ago. I am particularly struck with the appearance of everything here being finer than we see them in the provincial towns. Shops, horses, carriages, men, women, children, all seem of a more perfect sort than we see them elsewhere. I do not believe that two millions of people can be found *together*, or in one continuous country in the world, to match the population of London. Perhaps the way in which the population is kept up from the country is something in practice like picking; i. e. that those who come here are above the average standard of excellence.

You wish me to write to you what Mrs. Grundy is saying of us Americans. The Mrs. Grundy that I have as yet seen in the country is not acquainted with us. She does not know enough of us even to talk good scandal of us. But I shall probably soon hear the old lady in London, who knows us better, and I will make report of her to you. I find I have several drops of American blood. I discovered it in Liverpool, where a gentleman asked me about the Mexican war, and whether the American people could approve it. I told him no. That they thought it entirely wicked, and not to be defended, — as bad even as the English war upon China. . . .

Very sincerely yours,
D. Treadwell.

To Mr. Francis C. Lowell.

London, October 1, 1847.

Dear Sir, — In my former letter, by the steamer of the 4th of September, I informed you that I saw no reason to change from the course intended, when in Boston, to be pursued on arriving here, — which was to send my pamphlets to many of the men of authority and influence here, and wait the result. To find who were the individuals most likely to take the business up, I supposed that Colonel A. would assist me. I found him of no use, however, and was obliged to do without help. I therefore wrote letters to the Secretary of the Admiralty, and to the

Inspector-General of Ordnance, and enclosed them with about twenty pamphlets each to those boards. In my letters, I requested that the pamphlets should be given to such officers as they thought most likely to be interested in the subject, and said I should be happy to communicate further details and official verifications of the statements in the pamphlet to them, or any of their friends. With this I sent my address. I likewise sent pamphlets, with my address, to the Duke of Wellington, and several other officers, and to Mr. Faraday, Mr. Barlow, and several other philosophers and engineers. The utmost effect that has been produced by all this has been a letter of thanks from the Lords of the Admiralty, but no inquiry for more details concerning the cannon, or anything which would lead to a belief that they had a thought of adopting it. As I can see no way for pursuing the subject further with any hope of success here, I have concluded to pass over to Paris, and see if it be possible to move them to anything there. I hope that you will think that I have done all that could be done usefully, for although I have long since, as you have perceived, lost confidence of success, I have determined to go through the effort of striving for it in the same way that I should do if under the stimulus of hope. . . .

The last steamer brings us the sad news of the death of Mr. Patrick T. Jackson. His loss is irreparable to you and his immediate friends, and to be severely felt by the whole community of Boston. . . .

It appears by the last accounts from Boston, that the Mexican war prospers, if victories be prosperity. It is certain, however, that, atrocious as the war is, our success has created here a greater respect for the American character than was entertained for it before the war was declared. This and the symptoms of further attempts to pay the State debts have advanced our reputation with all classes. . . .

DANIEL TREADWELL.

Mr. Treadwell arrived in Paris in October, and here it was much the same as in London, but he had more interest in observing the condition of the people and the buildings as compared with that at his former visit, twenty-seven years before. He at once set about the great object of his present visit, and, with the aid of a letter of introduction from Mr. Isnard, the French Consul in Boston, put himself in communication with the artillery officers at the castle of Vincennes, to which his cannon had been sent nearly two years before. A Commission had been appointed by the Duke of Montpensier in the preceding April to prove the gun, and something had been done towards this object before Mr. Treadwell's arrival. But the work went on with the proverbial slowness of government officers, and his patience was sorely tried. However, he visited the castle from time to time to keep himself informed as to the progress of the proof, and the impression made upon the officers in charge.

TO MR. FRANCIS C. LOWELL.

PARIS, October 30, 1847.

Dear Sir, — I wrote to you a hasty, though long, letter by the French steamer of the 24th, which I trust you will have received before this (which I shall send by the way of Liverpool) reaches you. You will know from that letter all that had passed here concerning our cannon up to that date, — that some trials had been made, a part of a full set of experiments ordered under a Commission from the Government, and that so far the results had been very satisfactory. I have thought it best to abstain from going to Vincennes, where the trials are made, from the time I last wrote to you until to-day, as my presence might be embarrassing to the officers, and at the same time might show a want of confidence in them which had better be avoided. However, as ten days had passed since I last saw the Commissioners, I went to the Castle to-day and found them in a neighboring coffee-house playing cards (*passer le temps*). They were very polite, and told me that since I was last there they had fired seventy rounds of six pounds of powder and one shot, that no effect was yet produced upon the gun, no lodgment as yet, and that they continued perfectly satisfied. On inquiring how long before they should get through with the proofs, they said it would probably take till February; that they should then make a complete report of the facts to a general officer, who is at the head of the Commission, who would afterwards make another report to the Minister of War.

You will see that this is just the dilatory course that I predicted in my last letter would be pursued. Any remonstrances against it would be useless, and perhaps improper, and so what cannot be changed had better be submitted to with a good grace. I shall express no dissatisfaction to the Commission at their slow operations. It was my intention, you know, when I left home, to spend a few months in Italy before my return, and I shall perhaps conclude to take this time, which must otherwise be passed to no account in Paris, to accomplish that object. If I conclude to do this, I shall go very soon, so as to return in time for the report of the Commissioners in the spring. They will, I have no doubt, inform me of their progress during my absence. They appear now well disposed towards me, and highly pleased with the gun, and I think that my absence will appear to them as a show of confidence, which will operate in my favor in their report, more than anything I can do by staying about them. No officer has yet been found at Vincennes who could get through with my pamphlet. They introduced me to one to-day who reads a little English, who said he was laboring at it, and had mastered half of it. Yet many of these officers are from the Polytechnic School, and perhaps half of them know something of calculus. You will see that I have not absolutely determined on leaving, in the present state of the experiments, for Italy, though my mind tends that way. I shall consider it yet more carefully, and visit Vincennes again before my final conclusion, which, whatever it may be, I hope you may approve. . . .

DANIEL TREADWELL.

"After finding," says Mrs. Treadwell, "that they had learned something of the merits of the gun, and were favorably disposed, he seemed to think mostly of the pleasure of the Italian journey before him. We took the route through Arles, Nismes, Avignon, to Marseilles. The grand old Roman ruin of the aqueduct of the Pont du Gard, the amphitheatres of Arles and Nismes, the Maison Quarrée, and the Papal Palace at Avignon, where we recognized Dickens's old woman, who showed us the oubliettes and acted the death of the prisoners, just as she did for Dickens, — all these interested him greatly. In Italy he seemed to forget that art was for any other purpose than to embellish life, and gave himself up to the enjoyment of pictures and statuary as entirely as if he never modelled a gun or worked a printing-press. But he did not forget to examine a piece of ordnance whenever it chanced to fall in his way, sometimes not very successfully. In Naples he one day attempted to examine a cannon guarding one of the great squares, and began measuring it, when he was instantly seized by some of the officials, and peremptorily ordered to fall back under penalty of being taken for a suspect if he persevered. We spent many days (without our party) at Pompeii, Mr. Treadwell measuring and examining the construction of the houses and baths, and taking great delight in looking at the things found in Pompeii, now collected in the Museum."

While in Europe he wrote the following letters to his old friend, Dr. John Ware.

To Dr. John Ware.

Paris, November 12, 1847.

Dear Sir, — Your letter by the steamer of October reached me soon after my arrival here, which was on the 8th of October. . . . So we are in Paris, centre of fashion and the high science of the world. Twenty-seven years ago I was in the same city, and within a thousand feet of the spot where I now write. The great buildings and streets all appear to me as old acquaintances. Some of the signs of the shops even I remember. I notice, however, an evident improvement in the moral aspect of certain orders, and a great accession to the power and comfort of the people by the adoption of English inventions in the arts. For example, I crossed the channel in a steamer, — English with a spice of American. I came from Abbeville to Paris by railway, — English. The wires of the telegraph pass over the whole line, — English or American, or both. I entered Paris in the evening, and found it flaming with gas, — English again. And what have the French to oppose to these great Anglo-Saxon improvements which so strongly mark the present age? I can think of nothing more important at this moment than the Daguerrotype, and in this art the English form of Talbotype seems now to be getting the lead. For public works executed in Paris since 1820, there appears to have been none of greater importance than the erection of the obelisk and building the fountains in the Place de la Concorde. The Arc de l'Étoile is the greatest work of the kind I ever beheld, and I can well believe it is what the French claim it to be, the noblest arch in the world. Indeed, I hardly supposed such a structure capable of so much grandeur of appearance. But is it not a striking fact, that of all the hundreds of names of victories and battles with which it is covered, there is not one mentioned in which the opposing force was English or mostly English, while Nelson and Wellington have filled England with names and monuments to record the triumphs of the English over the French. But I am talking the French down when I am getting to like them more and more every day. . . . You of course went many times to the meetings of the Institute. I cannot therefore give you anything about this most distinguished body which will be new to you. I have attended at three of its meetings, and as it is without dispute the highest, or perhaps more properly the most select, scientific body in the world, I could not but be closely attentive to all that I saw. It did not seem to me that the members presented that superiority of appearance over ordinary men that one would be likely to expect to find from their superior intellect. The heads, though good, are not strikingly so, and I saw no head equal to Webster's or Bowditch's. I was particularly struck with the appearance of Arago, who is one of the best-looking men in the assembly, from his strong resemblance to your father as he was fifteen years ago, though Dr. Ware was the superior-looking man of the two.

Leverrier, whom you probably did not particularly notice, as he has come to his fame since you were here, is quite an ordinary-looking man, — not a single strong mark of superiority that I could see either in head or face, but an appearance somewhat like a New England railroad conductor, or the bustling keeper of a country store. He has taken a great part in all the meetings that I have attended, in one of which he read a paper of an hour on comets. He speaks very plainly and distinctly, so that I could follow him in a part of his paper. After he had concluded his piece on comets, old Biot took exception to some of his statements, and there was a little passage of *words* between them. At another meeting Arago checked him for finding fault with Mr. Hind's observations of his (Hind's) new planet. Leverrier became very impatient both times, and evidently feels his importance. His merit is no doubt great, but his luck has been greater. The medical members of the Institute struck me as a particularly rough-looking set. With the exception of Roux, I did not see one who would be taken for a first-rate gentleman, or *aristocrat,* in England. Indeed, the whole body appear little attentive to dress, and many small observances which are thought indispensable with men of the higher classes in England. Their coats wanted brushing, and their hands seemed unused to gloves, — contrary to American and English notions, as we have considered the French as highly artificial in dress and manners, whereas the same class seem to me much less so than in England. This is of course of no more importance as affecting the character of the Institute than the color of Milton's coat affected the character of Paradise Lost, but I notice the fact as so.

W. Morton's man is here with a memoir on Morton's behalf as the discoverer of the use of ether. It seems to be Morton's last paper, translated into French. The Institute have referred it to a commission. Ether is in universal use here. I was at the Hotel Dieu a few days ago, and the operating-room was full of its odor. I asked the attendant if they used it in all operations. "Oui, toujours, toujours," was his reply. In England B. C. will not use it at Guy's Hospital. He says the patients do not do as well when it is used, and Dr. Boott told me that L. some time since gave it up, as he found it would take more time than it would to perform the operations without it, — and this is probably the cause of C.'s not using it, — but afterwards, finding that the public would have it, he was obliged to resume the use of it. Many of the first dentists will not use it, on account of the trouble and the offensive odors in their houses.

I see instances every day of the French character, particularly in the lower orders, where national character is alone to be found, which I admire; amongst these is the willingness to get a livelihood by any means of honest industry, without being ashamed of their calling. The boot-black and the *chiffonier* do not lose their self-respect by their trades, and I honor them for it. Again, the kindness of all classes for horses and dogs is beautiful. I saw twenty of the best-dressed men go off the Boulevard the other day to help up a poor horse who had fallen under a load. Who ever saw a like sight in London?

When this reaches you, the United States will be in a fever of excitement for the action of Congress upon the Mexican War. The noise of this, however, will not be attended to on this side the water, as the affairs of Italy, Switzerland, and above all Great Britain, will for some time form the chief subjects of interest here. Parliament is to assemble soon, when the dreadful state of the poor in England and Ireland will be brought before them in some form, with attempts to give relief by legislation; but the evils, if there is any truth in the accounts that are universally told of the condition of Ireland, are beyond the reach of constitutional laws, and can only be overcome by a recurrence to a division of property, or an entire change in the management of the proprietors.

Before making up my letter I cannot forbear to notice your *flare up* at the account I gave of Wordsworth's remark about Mr. Prescott, and the inference I drew from it. But I doubt if you were exactly in earnest as to the comparative reputations of these two great men. Nothing more is wanted, indeed, than your own statement of the way in which Wordsworth has advanced to his present eminence, to prove that he possesses the merit of *originality* at least. To say that a man is fifty years in making his way to the public favor, is to say that he is fifty years in advance of the public mind. As to your assertion that he is now famous only with a clique, show me the journal or critic now that speaks of him without reverence. For Mr. Prescott, I shall not deny him the merit of a fine taste, and an artistic power of style and arrangement, for which his works are admired by a great number of cultivated readers. But is an artist of this kind to take rank of an originator of a new kind of poetry, which he invents and builds up, and obliges the public to receive as an addition to its literature? But you were in joke when you made the claim, and if you were not, I cannot write you down across the Atlantic, but must leave it for a bone to pick on my return. I wish that your letter had been more explicit upon the microscope; you do not positively request me to buy one. I have determined to do so, however, and you may expect to receive it by the Versailles from Havre on the first of January, and if you do not like it, why, I will take it and "play the part of Orion myself" when I settle down upon Connecticut River. . . .

Very truly yours,

D. Treadwell.

To Dr. John Ware.

Naples, January 23, 1848.

Dear Doctor, — I received yours of the 14th of December at Florence, and hope there are others on the way for me; for as I am now beyond the reach of American newspapers, I depend upon the Cambridge letters entirely for all that relates to the world to which I belong. I can ask you to write with the more freedom, as with you "writing comes by nature." I, on the contrary, am descended from the hermit of Prague, and hate pen and ink.

Our residence in Florence was very satisfactory. Of course we could have little or no intercourse with the Florentine people, and were, like most other foreigners, confined to the outside of things, and to the world of art, which gives to Italy its eminence, and perhaps forms one of the causes of its degradation; for how can a people who think a picture a greater affair than a steam-engine, or an opera of more importance than a treatise on the freedom of the will, ever advance the true power of the race?

We have found the usual discomforts of an Italian winter. Great open rooms and miserable fireplaces contrast strongly with our tight parlors and *scientific* grates and stoves. We have hardly found a door in Italy furnished with a good lock and hinges. Michael Angelo said the bronze gates of the Baptistery of Florence were worthy to be the gates of Paradise; but if transported there, St. Peter will find a deal of fault with their locks and hinges.

We came to Naples by the steamer, touching at Civita Vecchia, where the only lion in vogue with travellers is Gasparoni, the great robber, who was taken with his company twenty-four years ago, and has been kept in prison ever since. He was accused of a hundred murders, but he declined the honor of the full number, confessing only thirty-four. We saw him in the open prison, and found him very merry, and, except what seemed like a little of the laughing hyena in the eye, he appeared like other men. He permitted me to examine his head, in which I discovered no remarkable developments except in *veneration*, which rises almost to a deformity.

He declared himself (on being asked) a good Christian, and probably thought himself so when in the midst of his career.

We have been to Pompeii and Herculaneum. I found the space uncovered much larger than I had supposed it to be, and the remains much more perfect and of much higher art. The sight, however, did not produce the deep feeling which came over me at the Notch House of the Willey family (White Mountains), — probably because its period is so remote, and, moreover, it belongs to a mode of life so different from ours that I could not bring the actors before me as I could those in the Yankee bar-room.

On leaving Naples, we shall go to Rome, pay another visit to Florence, and then to Venice and Milan. After this, as we cannot pass the Alps for some time, we may go to look after the "German mind" at Vienna and Berlin, as we can have a railroad all through Germany. . . .

We have found a great many Americans in Italy, and indeed there seems to be a greater show of Americans at the hotels than of English. By the by, if you see Mr. Worcester, I wish you would ask him to strike the word *interesting* out of his Dictionary; the Yankees abuse it more than they ever did *guess*.

Notwithstanding all the queer things that hang about us, we show our superiority to this Latin race, and appear amongst them as lordly as John Bull. "I 'll tell you what," said a Virginian, "these *Ital-lians* have the big works, but we have the big hearts." There may be a future in which Rome will be annexed.

Yours faithfully,

D. Treadwell.

To Dr. John Ware.

Paris, May 15, 1848.

Dear Sir, — My last letter was to Mr. Rice from Vienna, about the 25th of April, and a day or two after we left for Prague by railroad. Then down the Elbe to Dresden; through Leipzig, Halle, Weimar, Erfurt, and Gotha, to Eisenach, by rail; to Frankfort by diligence; to Mayence by rail; by steamer to Cologne; then to Brussels, Liege, Amiens, to Paris, stopping, of course, at all the important points, and giving the usual day to Waterloo. The weather was uniformly fine, and the journey altogether pleasant and instructive. I find I was more wrong in my ideas of the German people than in anything else I have seen. They are higher in civilization, in art, and with apparently a more comfortable distribution of wealth, and the means of enjoyment, than I had supposed it possible for them to be. I believe if the whole German people were united under a wise federal government, they would be the first nation in wealth and power on the Continent. Perhaps in mere fighting power the hot-blooded French might go before them; but in all which constitutes the power of a nation at peace, the Germans, I think, would take the lead. They seem now to be advancing in the course of true reform; and although it has been attended in several states with violences which have for a time paralyzed all law and government, it was the only way in which anything could have been done. The crowns have never yielded to the people, and never will yield a step for their good but upon compulsion.

We found Paris in a state of excitement and fever that is fearful to think upon when one calls to mind the scenes of the first Revolution. The people seemed like madmen broken loose from their keepers; and yet there is a certain kind of order and confidence in the continuance of personal security. I have remarked elsewhere — in Italy, Germany, and here — the great influence which past discipline yet possesses in controlling the people. Society is now governed and order maintained without any real efficient law; but things go on from the old impulse, as a body in the physical world continues to move from its inertia, until opposing forces bring it to rest. The same must happen in the world of men. Every day the old impressions of the necessity of order, and the habits of obedience to some rules of regard for the rights of others, will become weaker; and unless some government of real power is established, neither persons nor property will be safe. Not that I believe the frame of things will be disjointed forever, but that a state of lawless anarchy will be introduced, and will continue some time before the great class who are always in favor of law and order, but who are always timid, shall see the necessity of a decided course to put things right, and to that end are obliged to resort to force.

Nobody yet knows into what parties the National Assembly will divide. The members all cry, "Vive la République!" but it is said that many of the members are Royalists; some for Henry V., and some — a much smaller number — for the little Comte de Paris, with his mother for Regent. Royalism, however, if it exists, is entirely smothered in the enthusiasm for the Republic, and the great present struggle is between the National, or Moderate Republicans, and a mass of opponents made up of Democrats, Communists, and all sorts of impracticables and Utopians, who carry the mob of Paris, and consequently have a physical strength that keeps the sober-minded in constant awe.

May 16th.

We yesterday had a decided outbreak, of which although you will have enough in the newspapers, I will put down a short account. The ultra democrats, of all kinds, have for some time been excited by their clubs to unite and overawe the National Assembly to make war for Poland. The leaders seem to have taken this as a rallying point of opposition to the moderate party, and from it they hoped to break down the National Assembly. After three or four preliminary meetings in the Place de la Bastille, they yesterday assembled there, in full force, to carry petitions for the Polish war to the Assembly. Our lodgings are on the Boulevard Montmartre, and we saw from our balcony the procession pass to the chambers. I believe that it consisted of *a hundred thousand persons.* About three quarters of them wore *blouses;* many of the remainder had the uniform of the National Guard. There were some dress-coats, and some — perhaps in all more than a thousand — *women.* None were armed externally, though it was said that most of them had concealed weapons. They had hundreds of banners, and thousands of them were singing the Marseillaise and other choruses. The crowd upon the Boulevards and at the windows did not salute them or answer their shouts. They went directly to the National Assembly, where the leaders obtained forced admission, the commander of the National Guard, General Courtais, having neglected his duty and the orders of the President of the Assembly to oppose them by force. They broke through the doors and inundated the halls and galleries. They dispossessed the members of their seats, overturned the President's chair, the tribune and clerk's tables, and put an entire stop to the government for many hours. In the mean time another party went to the Hôtel de la Ville, and, taking possession of it, proclaimed a provisional government of some eight or ten of the most furious demagogues. Towards night, however, the tables were turned, the *rappel* was beat, and the National Guards assembled from all quarters. Masses of them went down the Boulevards, in sight of us, shouting, "Vive l'Assemblée Nationale!" The shout was answered with enthusiasm from the people in the streets, and from the windows and balconies of the houses, accompanied with waving of handkerchiefs and all other signs of approbation, which contrasted strongly with the silence in the morning during the passing of the hundred thousand *Blouses.* The National Guard soon cleared the hall of the Assembly of the mob, and reinstated the members of the Assembly, made prisoners of Blanqui-Barbès, Sobrier, Raspail, and their own general commander-in-chief, Courtais, from whom they took his sword and epaulettes, and placed him under guard, charging him with treason in permitting the Assembly to be invaded. By this noble and seasonable rally the National Guard has saved the government for the present from dissolution, and Paris from blood. For several hours all was panic. The anxiety about the Bourse was remarkable; the people were running to and fro as if their last hour had arrived; government stocks fell four or five per cent, and many other securities almost as much. But to-day confidence is restored. The *rappel* was beat at an early hour this morning, and the *poor* National Guard again assembled in all the streets. Bodies of them were placed in the gardens of the Tuileries, which were closed to the public, and in the Place de la Concorde and all the other public places. The sittings of the Assembly were declared permanent. At the same time they passed a decree authorizing the prosecution of such of their members — Barbès, Albert, and General Courtais — as are accused of taking part with the insurgents yesterday. At present, then, all is quiet, and the government is strengthened by having put down a faction that threatened its existence. But this faction will probably rally; all its clubs will be at once at work, and no one can tell how soon it will be prepared for another outbreak. In truth, France is disorganized, and possibly the only way to an efficient organization is through another anarchy and another despotism, like those of the former Revolution. But we will hope. One thing is certain, that all business will be destroyed under the present state of things, as all industry is at an end. The National Guard, who form the most efficient of the industrial class, are constantly called from their business to quell disturbances. Then a great many of the journeymen have got notions of Communism, or the establishment of government manufactories, in which all shall share alike, into their heads; so that they will not work in their old way for their old wages. Thus from one cause or another there seems to be nobody actually at work, or at least the falling off in productive labor is seriously felt in France, and it has instead idleness and insubordination. You have more faith in the good sense of the *people* than I have to bring all right; but I think that the text of the Democrats, "We have destroyed the feudalism of the chiefs, we must now destroy the feudalism of the Bourgeois," is very dangerous, as it may end in something like dividing the *Pavilion* [Dr. Ware's estate in Boston]. Not exactly, but something like it.

PARIS, May 17th.

Paris is entirely quiet to-day. The *true men* are in great spirits, and believe that the factions are crushed. Several of the leaders of the mobs are in the Donjon at Vincennes, — the old military fortress where the Duc d'Enghien was tried and shot. The Revolution does not yet appear to have thrown up any great and leading mind to which all others give place, either from respect or fear. It seems a sort of destiny that civilians cannot succeed in this way. Lamartine has had a little run of popularity, but I think it must be seen from his reports that he is not man enough for the crisis. Arago has a certain degree of popularity, but the Parisian tradesmen say that he knows more about the moon than he does about France. Probably the great one is now in the Polytechnic School, or, if that is too young, with the army in Algeria.

What an opportunity was thrown away by that false-hearted Louis Philippe! Had he been true to the principles that placed him upon the throne, had he been a patriot king, France would at this time have possessed a well-consolidated liberal government in peace and prosperity, and he "that which should accompany old age, As honor, love," etc.; but now an unpitied exile, for I have not heard a person in France drop a word of pity for him; on the contrary, all say he has only got his deserts.

I am grieved to learn that Judge Kent has left Cambridge. There was something *real* and hearty about him, and he will be a great loss to the good-fellowship of the place. I enclose a "bill of the play" showing natural history exhibited on the Boulevards. After you have read it, send it, with my regards, to Dr. Jeffries Wyman. The exhibition is very curious.

Yours very truly,

D. TREADWELL.

In the summer of 1848, finding that nothing further could be done towards introducing his guns, Mr. Treadwell returned to Cambridge.

TO COLONEL GEORGE TALCOTT.

CAMBRIDGE, September 3, 1849.

Dear Sir, — Since my return from Europe, which is now about a year, I have expected and intended every month to go to Washington, where I promised myself the pleasure of seeing you. But something has constantly occurred to prevent my journey. Being assured, however, that you have not forgotten me, by your frank enclosing a pamphlet to me, the other day, and for which I am much obliged, I can no longer delay writing to you to communicate something of my cannon affairs abroad, as well as some other information that I wish to place in your possession.

The French Government of Louis Philippe made a long course of trials on the thirty-two pounder that I sent to them at Vincennes. They did not however carry the proofs to extreme charges, which they were preparing to do when the Revolution put a stop to that and all other experiments. The Commission reported upon the trials made,* and were highly satisfied with the performance of the gun, never before having seen a piece stand unaltered the same number of charges. All this, however, proved of no advantage to me, and, being satisfied that nothing more would be done in the unsettled state of the government, I was constrained to give up the further pursuit of the subject. In England I did not expect to obtain even an examination of the invention, and none was made. Thus rests the unfortunate project, about which, however, I hope to have the pleasure of talking with you verbally before long. . . .

DANIEL TREADWELL.

The other matter referred to is a method of constructing torpedoes of great destructive power, confidentially intrusted to Mr. Treadwell for communication to the Ordnance Office of the United States.

Here ended all efforts to induce our Government to adopt the most important improvement, if not the only improvement, in the construction of heavy ordnance since the reign of Queen Elizabeth.

The gentlemen associated in this enterprise believed themselves warranted, on business principles, in assuming that the Army and Navy would secure the best armaments. In this they were mistaken. Although the guns had been proved superior in strength and endurance, to any before made, the number ordered did not warrant any probable expectation that they would prove remunerative.

---

* See Report in Appendix, No. IV.

The following is a summary of the guns manufactured by Mr. Treadwell: —

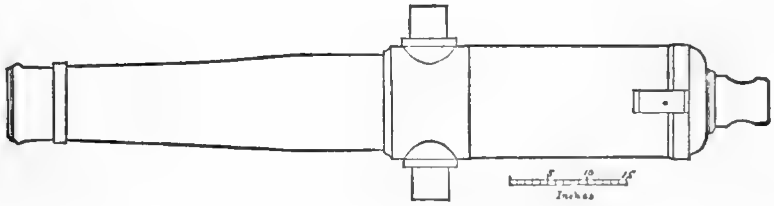
> "Of the guns with a lining of steel, the wrought-iron bars being wound upon a previously formed steel ring, eight were six-pounders of the common United States bronze pattern, and eleven were thirty-two-pounders of about eighty inches' length of bore, and eighteen hundred pounds' weight. Six of the six-pounders and four of the thirty-two-pounders were made for the United States. They have all been subjected to the most severe tests. One of the six-pounders has borne 1,560 discharges, beginning with service charges and ending with ten charges of six pounds of powder and seven shot, without essential injury. It required to destroy one of the thirty-two-pounders a succession of charges ending with fourteen pounds of powder and five shot, although the weight of the gun was but sixty times the weight of the proper shot."

Besides these, several guns were made on Mr. Treadwell's own account.

The buildings in Brighton were never occupied for the purpose intended, nor for any purpose, except for a short time in 1848 as barracks for the volunteer soldiers of Massachusetts returning from the Mexican War. The machinery and tools, together with the buildings, were sold in 1855, the land in 1864, and the whole project ended with large loss to the company.

Mr. Treadwell in his Autobiography says of the result of his long and costly labors: "Few men look with kindness upon a projector by whose plans they have sustained a loss of money. The kindness of my friends in this case, however, has seemed to increase with our disappointments, and I cannot forbear to name amongst them Mr. Francis C. Lowell, who, since the abandonment of this design has treated me as though the failure were due to an error of his own, rather than to any miscalculation of mine."

One of the thirty-two-pounders was presented in 1874 to the Institute of Technology, in Boston, on which is inscribed, "Daniel Treadwell, Inventor and Maker, 1844."



TREADWELL THIRTY-TWO-POUNDER. — MASSACHUSETTS INSTITUTE OF TECHNOLOGY.

Francis C. Lowell, Esq., also has a thirty-two-pounder, and the editor of this Memoir a four-pounder.

After Mr. Treadwell had ceased to expect the adoption of his cannon by the Government, his principal business was the management of the affairs of the Spinning Company. The work at the Mill-dam was to him no pressing labor; it was a pleasure. As he wrote when in Europe to Mrs. Treadwell: "I like to hear of it, for at the sight of the name of the Gypsey I hear the humming of the wheels." It might well give him pleasure, for its products were at once his pride and his profit.

His health required of him during the most active period of his life rest and recreation at short intervals, and these he found in frequent journeyings. Mrs. Treadwell says of him: —

"Whether during his lectures at the College, or when at his machine-shop, country drives were among his greatest pleasures and benefits; he used to say, 'I must ride for my life.' Some of these excursions with friends were of several days; setting out in our 'carryall' without a fixed plan, we would just go along pleasant roads that led to pleasant places. He always wanted a book when upon the road, and I very often, while he drove, read to him all day long; of course it was always some light reading. The beautiful valley of the Connecticut had such charms for him, that he even thought to fix his summer residence there, if he could persuade Dr. Ware to become his neighbor. It was when returning from one of these excursions, in 1843, that we fell by chance upon Howe's tavern in Old Sudbury. The quiet look of the place, shadowed by its grand old elms, caught our fancy, and, stopping for the night, we found the comfort of the interior as attractive as its outside beauty. It was so quiet, so utterly secluded, away from railroads and travel, and so free from other guests, that it gave him just the change and rest he needed. From that time till he went abroad, in 1847, he passed his Sundays here. Leaving Cambridge in his carriage on Saturday afternoon, he enjoyed his drive of fifteen miles along the old Worcester Turnpike, and returned on Monday morning. He would also often go for another day during the week. In this way for more than twenty years we spent more or less of every summer. We went early in the spring, and continued our visits till the cool autumn weather. Dr. Parsons was almost always with us. Sometimes we were accompanied by a party of friends; Mr. Longfellow has idealized them in his 'Wayside Inn.' * But often we would spend the whole summer's

---

* Mr. Longfellow in one of his letters says: "'The Wayside Inn' has more foundation in fact than you may suppose. The town of Sudbury is about twenty miles from Cambridge. Some two hundred years ago an English family by the name of Howe built there a country-house, which has remained in the family down to the present time, the last of the race dying but two years ago. Losing their fortune, they became inn-keepers; and for a century the Red-Horse Inn has flourished, going down from father to son. The place is just as I have described it, though no longer an inn. All this will account for the landlord's coat-of-arms and his being a justice of the peace, and his being known as 'the Squire,' — things that must sound strange in English ears. All the characters are real." But

day in the fields and woods, wandering about or sitting down in comfortably shaded places with our books, Mr. Treadwell listening, or talking to his dog Snap, always at his feet, or taking long walks about the country. In cooler weather the sunny side of protecting walls were our favorite spots; when at evening we gathered about the cheerful wood fire on the ample hearth, Dr. Parsons was the reader. Mr. Treadwell preferred listening to reading, except when the subjects were of science. He usually made me take the Iliad, a prose translation, which delighted him; the smooth versification of Pope's Odyssey charmed him when a boy, and he would repeat it page after page. Milton he did not like; Paradise Lost was to him only bad prose. He was a great admirer of Shakespeare, and among the best readers at the Shakespearian readings."

He mourned the loss of his Sudbury visits, to which he had become so much attached. To his friend Dr. Sweetser he writes: "The truth is, I have been rather drooping for most of the time since you were here in spring; and having lost my old resort of Sudbury (for poor Mr. Howe is dead, and his family of one hundred and twenty years' standing become extinguished, — all gone, — it makes me sad to write it), I have been obliged to seek out new quarters." And again, three or four years later, after he had been thinking of fixing upon the valley of the Connecticut for the summer months, and was then trying the sea-shore, he writes: "Pigeon Cove is not up to what Sudbury was in poor Howe's best days. But all that is now over. Howe has gone down and gone out, and Longfellow has immortalized him in 'The Wayside Inn.' I wish the poor old fellow could know what fame he has come to."

Mr. Treadwell at this time much enjoyed the Cambridge Scientific Club, an association of gentlemen, most of them connected with the University, formed for

they were not really at the Sudbury Inn. The musician was Ole Bull; the poet, Dr. T. W. Parsons, the translator of Dante; the Sicilian, Luigi Monti; the theologian, Professor Treadwell; the student, Henry Ware Wales; the Spanish Jew, Israel Edrehi. Parsons, Monti, and Treadwell were in the habit of spending the summer months there. (See Life of Longfellow, Vol. II. p. 398.)

Professor Treadwell is thus idealized: —

"A Theologian, from the school
Of Cambridge on the Charles, was there;
Skilful alike with tongue and pen,
He preached to all men everywhere
The Gospel of the Golden Rule,
The New Commandment given to men,
Thinking the deed, and not the creed,
Would help us in our utmost need.
With reverent feet the earth he trod,
Nor banished nature from his plan,
But studied still with deep research
To build the Universal Church,
Lofty as is the love of God,
And ample as the wants of man."

scientific, literary, and social purposes. The first meeting was held at his house in November, 1842. The regular meetings for forty-five years have since been held on the second and fourth Thursdays of each month, for the greater part of the year, at the houses of the members in rotation. The member at whose house the meeting was held at the same time read a paper, the evening closing with a supper. The paper — it has never been omitted — sometimes prepared for publication, was almost always connected with the reader's department in the University, or his profession, and was a subject of friendly criticism, both on its reading and at the table, where the most perfect freedom prevailed. The number of members was usually limited to twelve.† Mr. Treadwell rarely failed to be present at these meetings; he took a lively interest in the subjects brought forward, and his remarks upon them were serious and thoughtful. At the table he added to the general enjoyment by his good humor and ready repartee.

Subjects of Professor Treadwell's Papers.

November 14, 1842.	Construction of Cannon of large Calibre. First meeting of the Club.
October, 1846.	Percussion.
March 9, 1848.	State of the Arts among the Romans.
December 14, 1848.	Aqueducts of Rome.
November 22, 1849.	Friction.
April 18, 1850.	Stephenson's Tubular Bridge, Menai Strait.
December, 1850.	Precious Metals, particularly the Gold Mines of Russia and California.
September 11, 1851.	Second paper on Percussion.
November 18, 1852.	Captain Beaufoy's Book on the Increase of the Size of Vessel to gain Speed.
May 12, 1853.	Joseph Priestley.
March 23, 1854.	Discovery of America, — Columbus and Washington.
November 22, 1855.	Machinery of War since 1815.
October 30, 1856.	Scientific Societies.
December 10, 1857.	Ocean Telegraph.
April 22, 1858.	Ninth Bridgewater Treatise. Credibility of Testimony.
January 27, 1859.	Clocks and Watches.

---

† The following gentlemen were members of the Club with Professor Treadwell, from 1842 to 1862.

* Louis Agassiz.
* Charles Beck.
Francis Bowen.
* Charles Henry Davis.
Epes S. Dixwell.
* Edward Everett.
* Cornelius Conway Felton.
* Asa Gray.
* Simon Greenleaf.
* Thaddeus Mason Harris.
Thomas Hill.
* William Kent.
Joseph Lovering.
* Joel Parker.
* Benjamin Peirce.
* Josiah Quincy.
* Jared Sparks.
* James Walker.
* Emory Washburn.
* Joseph Winlock.
* Joseph Emerson Worcester.
Morrill Wyman.

Those marked with an asterisk are dead.

January	26, 1860.	Collier and Hamilton's Shakespearian Controversy.
May	10, 1860.	Instinct of Bees.
April	11, 1861.	Measure of Force.
January	30, 1862.	Captain Rodman's Book on Guns.

It will be seen that most of the subjects are those which Mr. Treadwell had long studied. The subject at the first meeting was the cannon upon which he was then laboring. To the other subjects, as force and those relating to the arts, a great part of his life had been devoted, and the results printed in the Proceedings of the Academy.

Of one of his papers, an essay on the Discovery of America, he says, "Wilfully, and you will probably say unwisely, by disregarding the aphorism that has been two or three times quoted in the Club, 'Let the cobbler stick to his last,' I have determined to present you a medley, for which I must deprecate any severity of judgment, if for no other reason, at least, that it is so far from my usual objects of pursuit." The views and suggestions of this paper were in his mind after a second reading of Washington Irving's Life of Columbus. The following extracts are from his concluding remarks.

> "We have here a great work produced, namely, a continent discovered; a great mind laboring with theories, opinions, and designs to produce it, and a certain stock of raw materials, namely, the facts that had been collected and the theories or opinions that were supposed to be established. These, that constituted the knowledge of the time, were elaborated by the mind of Columbus, and somehow or other a new world came out of them. I have spoken of the discovery of America as the most important since the period of authentic history. . . . Not mere geographical discovery, but discovery in any branch of human pursuit; I think I may go further, and extend the signification of the word discovery so as to include all the productions of human invention, and still claim for the discovery of Columbus that it has had, is having, and is destined to have a greater influence upon the condition of our race than any discovery or invention made by man since the period of authentic history. . . . An examination of the life, labors, and fame of Columbus is likely to suggest to any one a comparison between him and another great man whose name is most indelibly printed upon this continent, — Washington. No man can ever hereafter stand in the relation which Columbus and Washington sustain in connection with America. This continent can never have another discoverer, nor can any individual hereafter have the glory of being the principal leader of the founders of the first great American republic. . . . To pass from the question of personal qualities to that of the probable fame in after ages of Columbus as compared with Washington, we can conceive of nothing that can take place in or out of the country that shall diminish the importance of its discovery. Exactly as the population of America increases, the interest in the history of its discovery will increase. New States may arise and old ones may be revolutionized, the present order of things overturned, and the very frame of civilization new moulded, without changing the interest of its inhabitants in the history of that great event which established this race of man upon this continent. Can we be assured that an equally intense interest will always be maintained for the foundation of the great

republic? Suppose it to be separated, disjointed, exploded into the Northern, Southern, Eastern, and Western kingdoms or empires? The intense interest of the history of the Revolution will perhaps give place to history of the more recent, and it may be thought more heroic struggle, by which some new order of things shall be established and the fame of Washington swept away, or lose a great part of that living interest with which we now regard it and magnify it as a rich possession. This is the course that the man who looks to history as a teacher will expect of future ages. Young America is confident of other things. She looks to the republic extending itself under its present form, Southern institutions, compromises, platforms, spoils, and all, over the whole continent, thus adding the two poles to the two oceans in describing its boundary, and that thus the name of Washington would receive a universal connection with every part of the continent which has hitherto belonged to Columbus alone.

"Much as Columbus and Washington differed from each other in the character of their minds, there were two things in which they bore a striking resemblance,—personal presence and an earnest devotion to and constant sense of the importance of their labors. Both had the port and mien of beings of a superior race, that attracted all eyes and commanded all hearts. Both gave themselves up heart and soul to their work. That must be done. As to any personal sacrifice, such as loss of life in the attempt, that was not worth a moment's reflection. This gave a solemn grandeur to all that they did, and is to be found equally underlying the inventive genius of the one and the unerring judgment of the other."

It is not to be supposed that a mind as active as Mr. Treadwell's, associated with a determined will and never tiring perseverance, would lose its interest in that which had been one of the great objects of his life.

His health and strength were indeed impaired, but this did not prevent his engaging in investigations extending through several years, the results of which are embodied in a series of papers explaining the principles and methods of construction of a cannon now conceded to be the most efficient ever made. The first of this series, "On the Practicability of constructing Cannon of great Calibre capable of enduring long-continued Use under full Charges," was published in the Memoirs of the Academy, Vol. VI., 1856. Subsequently he writes:—

"Although my cannon of 1845 was a complete success in all that related to its construction, it was an utter failure as regards its adoption by the Government. That it was successful as a construction, I have only to say that Sir W. Armstrong, twelve years after I was obliged to abandon it, and after learning, as I fully believe, the method by which I produced it, formed his rifle cannon upon the same plan, and I defy him now, with the whole patronage of the British government, to produce a more perfect gun so far as *strength*, *soundness*, and *finish* are concerned, than I produced seventeen years ago by private means alone.* I limit my boast to the

---

* Whether Sir William Armstrong reinvented Mr. Treadwell's method and machinery for making these guns may be an open question, but it certainly might have been very easy for him to have learned them. Mr. Treadwell, in a note to his paper "On the Construction of Improved Ordnance," says: "When I first read an account of the method followed by Armstrong in constructing his gun, although I saw at once the exact resemblance of it to the method invented by me in 1840–44, yet not being aware of the fact that the specification of my English patent had been published *in extenso*, I thought it might be that Armstrong had reinvented my form of gun and the machinery required to produce it. But I have looked into that great work, 'The English Printed Specifications,' a copy of

above-enumerated particulars, for as to Armstrong's inventions in rifling and breech-loading he deserves, in my opinion, much credit for them, and I hope I shall be the last man to deny to another all that belongs to him.

"Although I was thus obliged to suffer the loss and shame of defeat, and abandon all that I had done, the mechanical theories upon which I had wrought and developed in practice had made a strong lodgment in my mind. I had early seen that the principal objection made to adopting my cannon lay in its price, and in the skill and attention that must always be required in its manufacture. To obviate these I proposed to myself to form a cannon of a thin cast-iron body surrounded by several layers of wrought iron or steel hoops placed upon it under *great strain.* I determined, by calculation, that this would be nearly, perhaps quite, as strong as my abandoned form, would come within the reach of ordinary skill, and would be in the long run cheaper than the ordinary cast-iron gun."

"I propose," continues Professor Treadwell, "to form a body for the gun, containing the calibre and breech as now formed, of cast-iron with walls of only about half the thickness of the diameter of the bore. Upon this body I place rings or hoops of wrought iron, in one, two, or more layers. Every hoop is formed with a screw or thread upon its inside, to fit to a corresponding screw or thread formed upon the body of the gun first, and afterwards on each layer that is embraced by another layer. These hoops are made a little less, say $\frac{1}{1000}$th part of their diameters less, upon their insides than the parts that they enclose. They are then expanded by heat, and, being turned on to their places, suffered to cool, when they shrink and compress, first the body of the gun, and afterwards each successive layer all that it encloses. These layers of wrought iron or steel hoops are placed upon the gun under *great strain.*" *

He laid great stress upon the accurate adaptation of the screw of the body to that of the hoop; he considered the difference between the thread of a screw cut cold, and the same thread when heated, and devised a machine for making screws with slight differences to obviate this very difficulty. A model of the machine is in the Observatory of Harvard College.

"The great idea which I followed in this construction is to place the material of which it is composed in an abnormal condition, that is, to place the inner portion under a state of compression, and the external portion or hoops under a state of great strain; and this is done to provide against the difficulty to which all cannon having their materials in a condition of equilibrium are subjected by the explosive effect of the powder rending the internal portion before any considerable strain is thrown upon the external portion. This condition, so far as I know,

---

which is in the Boston Library; and I there find that the specification of my English patent, enrolled July 5th, 1844, No. 10,013, was printed in 1854. The patent was taken out in the name of Thomas Aspinwall, then American Consul at London, who acted as my attorney. This specification was written by me, and transmitted complete to him. It occupies twenty-one large printed pages, with full references to elaborate drawings, which occupy a large folio plate, of the machinery used by me in constructing the cannon. [See reduced plate in Appendix, No. III.] Any one acquainted with what Armstrong calls his gun, and the mode of constructing it, will find here everything relating to it so far as its structure, *without rifling and breech-loading apparatus*, is concerned. There is no difference whatever in the form of the construction, the mode of putting the rings together within the furnace, or the tools and enginery required for the work except the substitution by Armstrong of a steam hammer for the hydrostatic press used by me. Now Armstrong has shown, by his denunciation of patents, to the British Association, that he is well read in the record of them; is it then probable that this has been overlooked by him?" — Memoirs of Academy, Vol. IX., 1864.

* See page 412 for method of making trunnion-bands in 1841–44.

was first pointed out by Professor Barlow, some thirty years ago.* In the cannon as constructed by me, I have provided a remedy for this condition, by which I produce as near as possible the result that all the substance of which the cannon is composed shall be equally strained by the explosive effect of the powder, and that no portion shall yield and rupture before every other portion has received the greatest strain that it is capable of bearing, that is, when the force is carried to the extent of producing rupture."

In making these hoops they are heated, and by forging brought to their proper dimensions; in this process they necessarily become annealed, and consequently inelastic. They must regain their elasticity and hardness to fit them for the purpose intended. This, as is well known, can be brought about by subjecting them to hammering or rolling. To ascertain the temperature at which this elasticity and hardness cease, an elaborate series of experiments was made with iron wire of different sizes, heated from 400° up to the temperature at which it is thoroughly annealed and its elasticity lost, that is, to a full red heat.

"These experiments demonstrate with some degree of precision several physical facts, all of which are of high importance in the construction of cannon upon the principle pointed out in the Memoir to which this is a sequel.† These facts are:—

"*First*, That with a piece of iron hardened by compression and tension, in the condition of hard wire, the amount of permanent elongation is far smaller than the permanent elasticity up to near the breaking point, and also that the permanent elongation does not begin until about one half of the breaking strain is applied.

"*Second*, That the part of the elongation, or stretch, which is within the elastic power of the wire, increases very regularly under equal increments of strain; thus exhibiting the truth of the maxim, *Ut tensio, sic vis*,—As the stretch, so the strain. But the permanent elongations made by the same increments of strain, especially when near the breaking of the wire, are entirely at variance with this maxim. This was shown in the experiment, where an increment of 20 pounds to an existing strain of 120 pounds produces a permanent stretch of $\frac{5}{16}$ths of an inch, while the same increment of 20 pounds, when the wire was under a strain of 280 pounds, increased the length, permanently, full $1\frac{1}{2}$ inches.

"*Third*, That, when the material has been subjected to a strain of a given amount (say 440 pounds), the repeated application of a strain within that amount produces no further permanent elongation.

"*Fourth*, That the subjecting of the same material to a heat sufficient to burn oil in contact with it (supposed in this case to be 800° Fah., at least) will not impair its elasticity.

"*Fifth*, That, when the iron is annealed, the permanent elongation commences at a comparatively low strain, and that its extent is very large in proportion to the elasticity of the iron, which shows how inappropriate is the use, upon a cast-iron body, of a hoop that has been heated to an annealing temperature; as it must be loosened, or suffer the cast-iron to break within its grasp, before a strain upon it up to half its tensile strength shall be reached."

"To construct one of the hoops for a cannon of the size before mentioned, that is, of 14-inch calibre, the hoop having, when finished, 27.972 inches' internal diameter, and being $3\frac{1}{2}$ inches

---

* The condition limits the size of guns made entirely of cast iron, as is seen in the Rodman gun, and led Mr. Treadwell to make the thickness of the walls of the cast-iron body of his gun only half the diameter of the bore.

† Memoirs of the American Academy, Vol. IX., New Series, 1864.

thick, and 15 inches long (or broad), I take a flat bar, say 14 inches wide, from half an inch to an inch thick, and of such length that, when wound into a coil, it shall form the thickness required for the hoop, after allowing for the waste in welding, forging, and finishing. After its ends have been scarfed to a long wedge form, it is to be heated to a low red heat, and then wound upon a cylinder of say 25 or 26 inches' diameter, as a ribbon is wound upon a block. Next, it is to be heated in a proper furnace to a good welding heat, and then, being placed upon an arbor, or mandrel, of about 25 or 26 inches' diameter, and between proper dies, sets, or swages, it is to be completely welded, or the several layers or coils are to be made to form one piece. This may be done by compressing it with the swages, by a hydrostatic press, or by a steam hammer. After it is properly welded and condensed in this way, and has cooled as low as 600°, it is to be placed upon a cold arbor, or mandrel (shown, in section, at *A*, *A*, Figures 1 and 2), which is supported at both its ends by the upright studs of the heavy iron frame *B*, *B*. It is then to be hammered by the steam hammer *C*, until its internal diameter is enlarged to about 27 inches. The last part of the hammering is to be performed after the hoop has become cold. Instead of operating in this way with the steam hammer, we may produce the same effect upon the hoop by a rolling-mill, in which the operating part of the rollers is made to project beyond the housings, or frame.

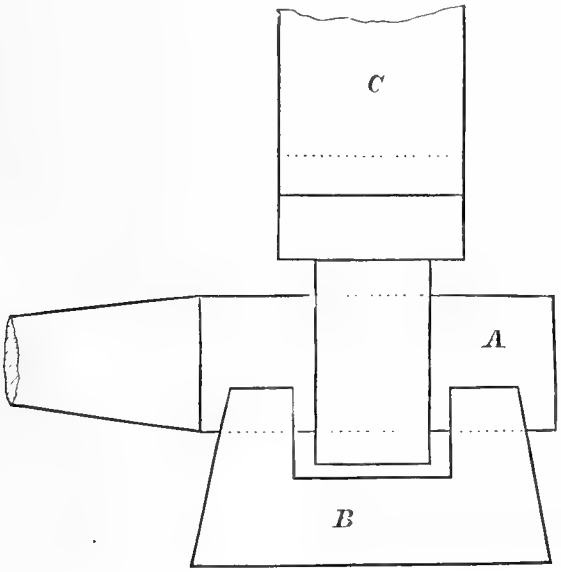


Fig. 1.

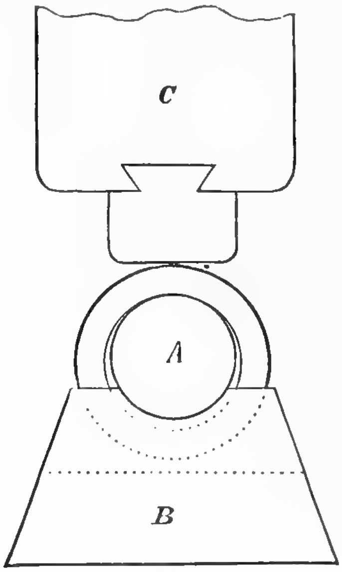


Fig. 2.

"After the hoop has been condensed and enlarged in this way, it is next to be placed upon an annular anvil, *D*, *D* (Figures 3 and 4), and the segmental swages or blocks, *E*, *E*, are to be adjusted within it. These segments form a cylinder upon their outer surface, but inside they form a hollow cone. A solid conical plug, *F*, is fitted to be driven into this hollow cone within the swages. With this arrangement, the whole being under the drop or steam hammer *C*, the plug is driven by repeated blows into the hollow cone, by which operation the hoop is stretched sufficiently to destroy all conflicting strains or tensions that might have been produced in it by the hammering. The strain is thus reduced to a circumferential direction, and the hoop put as near as possible into the condition of the hard wire, after it had been subjected to the first series of strains.

"The hoop may be stretched by this last operation the $\frac{1}{100}$th part of its diameter, and, if it is made of very soft and tough iron and has not been hammered very hard, much more than this quantity. The extent, however, to which this hammering and cold stretching may be carried, must depend upon the quality of the iron and the heating and working to which it has been previously subjected. It will be well, when the stretching is commenced, to have the hoop warmed up to 200° or 300°.

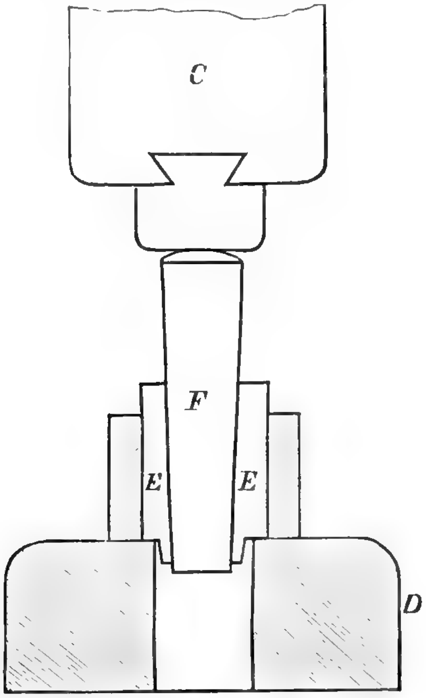


Fig. 3.

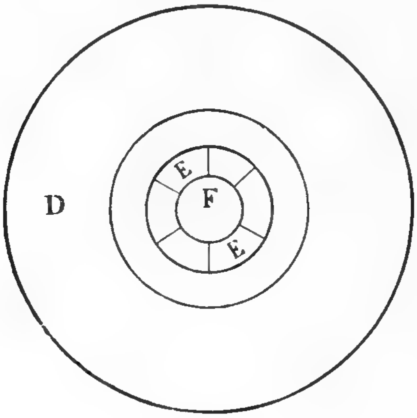


Fig. 4.

"After the hoop has been prepared in this way by cold hammering and stretching, it is to be bored and turned; and, whether it is to be fixed to the gun by a screw-thread, or by any equivalent, it is to be carefully and equably heated to such a temperature (but never up to an annealing heat) as shall expand it sufficiently, and, in this state, is to be placed upon the gun."*

"In the Specification and Memoir before mentioned, I propose to form the screw 'of about eight threads, each thread taking about one eighth of an inch space, so that one turn advances

---

* The method of making the rings and applying them is that followed in making the trunnion-bands in 1841–44, and for the same reasons, — for securing them and strengthening the guns. It is thus described by Mr. Treadwell: "All these guns that were finished had trunnion-bands screwed upon them by which the trunnions were secured to the gun. In order to utilize the strength of the trunnion-band against the force of the discharge of the powder, and to bring it in as an addition to the thickness of the body of the gun, the inside of the trunnion-band was in all cases made smaller than the body of the gun at the place upon which it was screwed. None of them could be got into their places when cold. They were therefore all heated to a small degree, and run on to the gun to their places while under the expanding influence of this heat. . . . The band, in each case, was taken across the road to the blacksmith's shop, and there warmed up, never to a red heat in any case. I should think always 500°, never 900°. No iron bars or tools were used in handling them, but the men took hold of them with cloth, and aprons, or anything of that kind which would defend the hand from the warm iron. I do not recollect ever seeing a cloth burnt in the operation." See Daniel Treadwell *vs.* Robert P. Parrott, United States Circuit Court, Southern District of New York, 1864.

each thread one inch,' and 'to make the threads of the female screws sensibly finer than those of the male, to draw, by the shrink, the inner rings together endwise.' The advantage of this form of construction will appear in this: that by the rapid advance of the hoop to its place, the shrinkage from cooling during its passage over the body will be avoided; while the dividing of the inch space of the spiral into several parts enables us to give a great bearing surface to very shallow threads. Small *splines* should be inserted under every hoop to prevent its turning by the recoil.

"I give here a drawing of the threads as I would form them for a six-threaded screw.

They have an .18 inch pitch, and a depth of .04 in., being .11 in. thick at the root or bottom, and .07 in. in breadth upon the face. Threads of this shape may be more easily and exactly made than any other, as a large part of the surfaces left by the boring and turning tools requires no change from the screw tool, but remains and forms the flat faces of both the male and female screws. By this means the gauged sizes and requisite diameters of both the body and the hoops are more easily ascertained and preserved, when the screw threads are formed.

"The depth of the threads given in this figure must be ample; for, as the threads, when once interlocked and in place, are kept in contact by the shrinkage of the hoops and the distension of the gunpowder, the idea of the outer threads slipping and riding over the inner ones, like a loose nut upon a screw bolt, is simply preposterous."

In the summer of 1854 he made a voyage to Europe. Soon after his arrival there the war began to rage in the Crimea, and he thought of bringing his invention before the French government; but as he could not well arrange his engagements so as to stop in Paris, he went to Italy. Reading there the accounts of the bursting of guns in the Crimea, he determined to go back to Paris as soon as possible to propose his invention of hooped guns to the French War Office, and addressed a letter to Maréchal Vaillant, Minister of War, stating that in 1845 he had manufactured for the United States guns of wrought iron, and that he at the same time made a 32-pounder and sent it with the aid of the French Consul in Boston as a present to the King of the French, and it was then at the fort of Vincennes. He requested that a learned and intelligent officer might be appointed to whom he could communicate new and improved methods which he had since devised. After waiting in Paris several weeks, and receiving no intimation that an officer would call upon him, he went to London, and after three weeks received a letter from a French officer who had been appointed to meet him.

Professor Treadwell on the receipt of this letter would have gone immediately to Paris and communicated his invention to the French government, but feared that the delay might occasion the loss of his invention in this country, as public attention was then turned both in Europe and America to improvements in cannon. He therefore concluded to take out the patent in America, and to that end sat down in his lodgings in London, and, without the aid of legal advice or books, drew up the specifications of his invention as it appears in the first patent issued.

While in Paris, he addressed a letter to the Right Hon. Frederick Peel, Secretary at War, asking the appointment of an officer or engineer of education and intelligence to meet him in London and examine his plans. In answer to this request Lord Panmure, on the 27th of April, 1855, directed Captain Lefroy, R. A., to meet Professor Treadwell at the War Department to receive any explanations he might be pleased to offer. By invitation he was also present at several meetings of the Ordnance Select Committee, at which were to be considered the subject of the fabrication of cannon of his invention. In June, Captain Blakeley, who had sought an interview with Professor Treadwell, was introduced by Captain Lefroy. Captain Blakeley informed him that he had some plans of hooped guns in his mind; but Treadwell as much as possible declined all communication with him upon the subject, as his own plans were completed, and he did not wish to reveal them to any one, nor to compare notes with any one who was upon the same subject. At that time no hooped cannon except "Mons Meg" at Edinburgh Castle, which was made of staves and wrought-iron hoops, (it was burst in firing a salute for the Duke of York in 1682,) was to be seen in any of the arsenals or depots of artillery in France or England.

He was satisfied from his observations at the Ordnance Office that the government had their hands full with their own men, and from these he was desirous of withholding all communication; it was also clear that nothing further could be obtained by being in Paris, for there again the ground was occupied by projectors whom their governments favored.

His reception in England at this visit was, however, very different from that in 1847; then he expected no attention from the Ordnance Department, and received none except the official acknowledgment of the "Short Account of an Improved Cannon," of 1845. He fortunately now made the acquaintance of Mr. Peter Barlow, the able writer on pure and applied mathematics and mathematical master in the Woolwich Academy; from him he received many attentions, which brought him into pleasant relations with several officers of the army and navy. These associations, however, did little to further the object of his visit, and in July, 1855, he returned to Cambridge.

Convinced as he was of the great value of the cannon of 1854, soon after his return from Europe he determined once more to attempt bringing it to the attention of the Government. For this purpose he first secured to himself whatever advantages might follow its use, and then made its merits generally known. He wrote a letter to the Secretaries at Washington, from which the following extract is taken.

> "Thwarted as I had been by most of the government officials and government boards, I had no heart to move in this matter practically at any great expense. Indeed, I had not the means

to permit me to do it, and I had already led others to spend more, from their confidence in my representations, than I chose to do again. No other course seemed open to me but to secure the invention by patent, publish an account of it with an exposition of its principles, ask the government to adopt it, and wait the event. Early in the year 1855 I determined to adopt this course, and in June of that year I completed my specification and drawings for a patent. In September I commenced writing an account of its structure and a demonstration of its strength. This account, although finished in November, was not, owing to several unforeseen hindrances, published until the beginning of 1856. As soon as it was printed, I sent copies of it to all the military and naval posts and stations, and especially to the ordnance officers at Washington. I likewise wrote a letter to the chief of the Ordnance Bureau, calling his attention to it, stating, amongst other things, that it must soon come up and be adopted in Europe, — that it must be taken up here in the end; — why not, then, commence now, and have the credit, if any credit should come of it, of leading the way in it, rather than be driven by others to the use of it? To this letter no answer or acknowledgment was ever returned.

"Again, two years after this, the rifled cannon made its appearance in England. To carry this out, Armstrong, as I have said before, constructed his gun after the method used by me eighteen years before. It now seemed to me that it would give us a great superiority over all the European forms of rifled cannon to apply the principle of the rifle-ball to cannon constructed after the method last proposed by me. So strongly was I impressed with this idea, that in February, 1860, notwithstanding my age and feeble health, I made the journey to Washington to urge it upon the authorities. I found them all as torpid as to any of the improvements of Europe, in rifled cannon, as they were to improvements in naval matters in the Sandwich Islands. I obtained, after a long and *im*-patient waiting, an interview with the Secretary of War, Floyd. He treated me courteously, though I saw at once that he knew nothing, and cared nothing, about rifled cannon. But as he requested me, on taking my leave, to put the substance of the statement which I had made to him in writing, I did so on my return home, and forwarded it to him. This completed my intercourse with him, though I afterwards printed my letter, a copy of which is herewith enclosed. Here the matter has rested, so far as applications from me are concerned."

The letter to the chief of the Ordnance Bureau above referred to was as follows: —

To General Joseph G. Totten, Chief of the Bureau of Engineering.

Cambridge, 1856.

Dear Sir, — Something more than ten years ago I had the favor of an interview and conversation with you under an introduction from Colonel Thayer upon the subject of cannon. I being then engaged in making a small number of wrought-iron and steel for the government. You were then extremely desirous of carrying the manufacture to cannon of very large size, instancing the celebrated guns at the Dardanelles as worthy of imitation, and lamenting that our Ordnance Department would not attempt with all our arts to produce guns equal to those of the Turks. My project, owing to the opposition of the old commodores, was not encouraged, and I was obliged to leave it in *abeyance*, although the guns made by me possessed a strength never before attained or approached.

The great attention given by the engineers and cannon-makers of Europe for the last two or three years to discover some way of making guns of great size, and the uniform failure of all their attempts, is not unknown to you. These failures have led me to re-examine the subject, and under the light of my former experience to devise a practicable method of fabricating guns of enormous size, that *must* fulfil all the conditions required for continued service. I forwarded to you some weeks since through the Smithsonian Institution a copy of the memoir in which I have examined the subject in detail and, as I think, demonstrated the perfect practicability of making a really great step in the power of artillery. I hope that you have found time to read this memoir, and if so I feel sure that, with your former views of the importance of the subject, you will not be disposed to let the improvement die. I have already in my former experiments expended too much time and money to dare again to enter upon it practically without official aid. Knowing the just influence that you must possess with the Government, from the confidence universally reposed in your great knowledge, may I not hope that you will give a project so accordant with your own ideas such an examination as its importance demands. An appropriation of a few thousand dollars would, I am perfectly confident, produce an instrument vastly superior to anything before known, and point out the true way of rendering our ports and sea-coast entirely unassailable.

Very respectfully your obedient servant,
Daniel Treadwell.

We have seen what became of the Treadwell gun of 1854 at the hands of our own Government. Let us now see what has become of it in the hands of other governments and other manufacturers, and for this purpose we will compare the methods of construction adopted elsewhere with those of Professor Treadwell above described.

Colonel E. Maitland, Royal Artillery, thus describes the methods of Armstrong as practised at Woolwich and Elswick in 1880, twenty-six years after Treadwell's publication. These guns are known as "built-up guns."

> "Wrought-iron coils are shrunk over one another so that the inner tube is placed in a state of compression and the outer portions in a state of tension, an endeavor being made to so regulate the amount of tension that each coil should perform its maximum duty in resisting the pressure from within. Further, the fibres of the several portions are so arranged as to be in the best positions for withstanding the pressures. It must be noted that a wrought-iron bar is about twice as strong in the direction of the fibre as across it. The exterior of the gun is therefore constructed of coiled bars of wrought iron welded into hoops and shrunk one over the other, thus disposing the fibre to resist the circumferential strain. These outer coils are shrunk over a hollow cylinder of forged iron, having the fibre running lengthway so as to resist the longitudinal strain. Within this cylinder, a forged breech piece, is placed a steel tube, gripped in like manner by shrinkage. This grand principle of gun construction is carried out by turning the inner coil in a lathe to an exterior diameter slightly greater than the interior diameter to which the outer coil is bored. The outer coil is expanded by the application of heat and slipped over the inner one. It contracts on cooling, and, if the strength of the two coils is properly adjusted, the outer will remain in a state of tension, and the inner in a state of compression. The number of coils is not limited. . . .
>
> "In making these coils *blooms* of iron are rolled into flat bars, which are fagoted together and rolled into long bars of the section required for the part of the gun for which they are

intended. These bars are then placed in a long narrow, reverberatory furnace, and raised to a bright red heat. When ready for coiling, one end is drawn out and fixed to a revolving mandrel, which pulls the bar out and winds it into a coil, like a rope round a capstan; it is then again heated and welded under a steam hammer: on cooling, it is bored and turned to the proper dimensions."

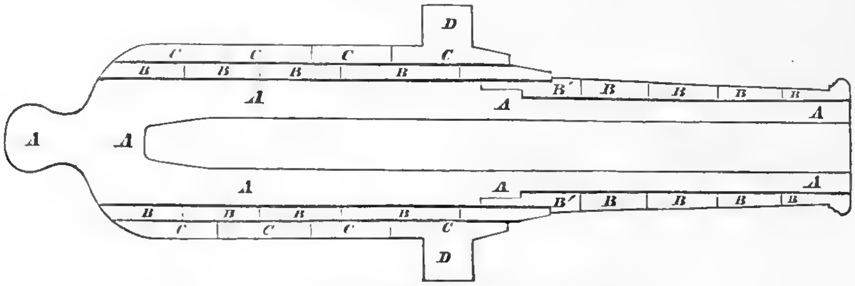
The Krupp gun also has a steel tube, but much thicker than the Armstrong gun, and in this respect still more nearly approaching the Treadwell pattern, with cast-iron body; over a considerable portion of the chase, hoops of cast steel are shrunk, the shrinkage being so adjusted that the successive layers of hoops shall support the body of the gun. The number of the hoops depends upon the size of the gun, usually greater than that of the English coils. They are secured in their places on the body by a number of *splines*, which prevent movement. The details of the manufacture of the Krupp guns have not been made public. It is not known that the Treadwell method of hammer hardening the hoops to restore their elasticity after heating is practised by Krupp; nor is it known that he used Mr. Treadwell's method of employing heated oil to determine the limit of temperature to which they should be heated when they are placed in position on the body of the gun.

Captain T. A. Blakely made a tube of cast iron resembling a gun, and over it forced with a hydraulic press one or more tubes accurately turned on the inside, of wrought iron. A gun thus made with hoops scarf-welded successfully resisted more than ordinary charges. Subsequently, after 1854, he adopted Treadwell's method of heating the rings and shrinking them on the body.

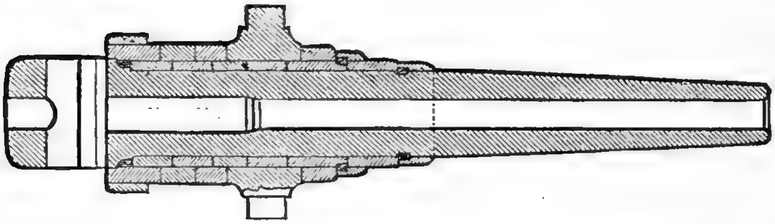
The Russian government has a foundry for guns of large calibre. These guns have a body of steel upon which are shrunk hoops also of steel; a twelve-inch gun weighing 89,296 pounds has forty-seven hoops.

The Whitworth gun is in its essentials made after the method of those just described. As already stated, he prefers, like Treadwell, hydraulic pressure to the steam hammer for his forgings.

Comparing these cannon with those made by Treadwell for our own Government in 1842, and those of his specification in 1854, we cannot but be struck with their close resemblance, both in the principles and method of construction. They are in fact substantially the same, — the same principles and methods upon which the strongest and most enduring guns are now made. The making of the hoops by winding the bar like a rope on a capstan, instead of a ribbon on a block, is not material as to strength. Indeed, as we have already said of the guns of 1842, we may now say of the guns of 1854: if all knowledge of Armstrong's methods were lost, they could all be restored, with the exception of the steam hammer substituted for the hydrostatic press, from Treadwell's specification alone.*



Section of the Treadwell Gun of 1855.



Section of the Krupp Breech-Loading Gun of 1880.

From the Encyclopædia Britannica, art. Gun-making, 9th edition. Except in the breech-loading apparatus, the resemblance between the Treadwell and Krupp guns is obvious.

Mr. Treadwell in his letter to the Secretaries, in 1862, writes: —

"It might have been said, when this plan was first promulgated, its principles pointed out, and its advantages demonstrated, that, however perfectly I had tested by practical trial the superiority of my guns made twelve years before of wrought iron and steel, no such practical test had been made upon the peculiar form last proposed (1854). This objection can now no longer be made. If I have been prevented or denied the opportunity of giving the practical test myself, others have partially done it for me. This has been effected, first, by Captain Blakely, an able and scientific officer of artillery in England, who filed a specification there soon after the date of mine, for an improved gun upon the same principle that is given by me. . . .

"Again, Mr. Whitworth, who has carried on such a sharp opposition to Armstrong, uses hoops strained on to the body of all his large wrought cannon."

Had Mr. Treadwell lived longer, he might have added to these the names of all the great gun makers of the world.†

---

* The process of making the Armstrong gun, and also that of the hooping of cast-iron guns, were seen by the editor of this memoir at the Woolwich Arsenal, in 1873, and were as above described.

† During the war of the Rebellion, many guns were made for the Government with a cast-iron body and a single wrought-iron band shrunk on to the body of the gun between the breech and the trunnions. The light guns, ten or twelve pounder field-pieces, did well, and illustrated the value of the hoop or band, imperfectly applied as it was. The heavy guns were a failure. The single band which was used was neither screwed, interlocked, nor splined to the body; it changed place and covered the vent; having been heated to 1100° F. in the process of manufacture, it was no longer elastic. When strained by the force of the explosion, it remained enlarged and no longer gave proper sup-

The following is the specification of the reissue of the Treadwell patent of December 11, 1855. It is dated February 4, 1862.

"I first cast a cannon in the usual manner, but having in its largest part a diameter only about twice as great as the calibre intended to be bored in it. I then bore it and turn the outside, making two or three cylinders as represented at A, A, in the drawing; one of these cylinders extending from the breech to a little beyond the trunnions, being somewhat larger than the others, that extend from near the trunnions to the muzzle. Upon these cylinders I cut a screw formed of about eight threads, each thread taking about one eighth of an inch space, so that one turn advances each thread about one inch. I then form several hoops or rings of wrought iron, represented at B, B, B, etc., in section. These hoops are turned upon the inside, and have a female screw cut upon their inner surface to fit the thread before described as cut upon the cast-iron cylinders forming the gun body. They are to be finished, however, about one thousandth part of their internal diameter less in diameter than the male screw that they are to encircle. They are then heated to expand them sufficiently to turn them on to their place or places, as shown in the drawing. It will be seen that the hoop marked B must be first put in its place and a portion of its outer side turned, and have the threads formed upon it before the hoop B′, that partly covers it, can be put in its place. When one cover of hoops (B, B, B, etc.) is arranged as herein described and shown, I place the gun again in the lathe, and turn the outside of these first series of hoops, and cut thereon a screw of several threads, as was before done on the cast-iron body. I then form another set of hoops (C, C, C, etc.), with female screws corresponding to the male screws upon the first series, and the diameter being one thousandth part less than the screw they are to cover. I expand them by heat, as was practised with the first set, and let them shrink on in place, as they are shown in the drawings. One of these hoops has the trunnions forged upon it, as shown at D, D. It will be noticed that the series C, C, break joints over B, B. The proportions in the drawing are intended for a cannon of twelve inches' calibre."

We give here the following letter from Captain Blakely, with Mr. Treadwell's reply, in conclusion of this subject.

To Daniel Treadwell.

24 Wilton Place, London, December 1, 1858.

Dear Sir, — I am going to read a paper to the United Service in January about our method of making cannon. Can you oblige me with any detailed account of experiments carried out with it in America by yourself or others? If so, you will greatly oblige me. I need hardly say that I shall duly acknowledge to whom science owes the experiments.

Our Government has now had an eight-inch and a ten-inch gun made for two years, but *has not tried either yet.* However, the experiments will soon commence now. The French have tried a thirty-two pounder, but did not put on the rings tight enough. However, the result even

---

port to the cast-iron body. Neither in the materials used nor in the method of manufacture, were the conditions obtained essential to secure the qualities of heavy guns constructed according to the Treadwell processes. The results were most unsatisfactory; eighty-six burst in the service, besides eighteen hundred-pounders unaccounted for, supposed to be burst, results widely different from those of the European manufacturers, who have intelligently and skilfully used Treadwell's methods. See Mr. Howard's Report of Joint Committee on Ordnance to Senate, February 15, 1869, page 217.

then was most satisfactory. A Mr. Smith, of New York, has taken a French patent for a slight improvement (?) on us. He makes his rings with a shoulder slightly dovetailed. When one is put over the other hot, it gives a little longitudinal strength. I *used* this plan for my wonderful nine-pounder, but think it unnecessary. I did think of having slight projections on the cylindrical part of the gun to fit with corresponding hollows in the rings, but I think now that the accuracy to be obtained by forcing the rings by hydrostatic pressure over a very slightly conical surface makes the best way.

I trust you will revisit Europe, and that I may have then the pleasure of seeing you. Meanwhile I hope to hear from you.

I am, dear sir, yours very truly,

T. A. Blakely.

To Captain Blakely.

Cambridge, January 29, 1859.

Dear Sir, — I am much obliged to you for your note of December 22, which I should have answered sooner but for a slight illness of myself and a more severe one of Mrs. Treadwell.

I am much pleased with your hopeful tone, and trust your account of triumphant experiments will not be lost upon the *ignorant* officials and the yet *more ignorant* public.

Your statement as to what passed between us at our first interview, when you did me the favor to call upon me in Margaret Street [London], early in May, 1855, is very nearly correct; only you do not take so much credit as I believe belongs to you as compared with Professor Peter Barlow.

To put the whole matter right according to my recollection and belief, I will give you a short history, but not to be published without my consent.

Before the year 1843 I perceived the unequal extension of a hollow cylinder when exposed to the strain of an internal fluid; and in that year I constructed a hydrostatic press of fourteen inches' plunge, having walls of cast iron of four inches in thickness, hooped with rings three and a half inches thick shrunk on. This press was used for making my wrought-iron guns, its force being one thousand tons; and I was then fully aware that a cannon hooped in this way would have all the advantages I have since claimed for it. I did not then suppose that the ratio, supposing the cylinder made up of a series of concentric rings, would be a diminution of strength exactly as the inverse square of the diameter of each ring, but simply as the inverse ratio of the diameter *plus* a quantity, whatever it might be, arising from the diminution of the thickness of walls produced by the distention. Soon after this, I saw Barlow's demonstration or paper upon the subject. I did not attend to it so particularly as to take a deep impression from it.

Not seeing my way clear to go on with the manufacture of guns, either of wrought iron or cast iron hooped with wrought iron, and the subject lay with me in abeyance until the winter of 1854–55, when, being in Italy and the war in the Crimea raging, I determined to make an effort in France or England, or both, to supply guns of great calibre of cast iron hooped with wrought iron, rather than of steel and wrought iron, like my first guns. I therefore went back to France, and, arrived in Paris, I addressed a proposal upon the subject to Marshal Vaillant, Minister of War, on the 20th of March, 1851. Not receiving the encouragement that I desired, I went over to London very early in May. I had in March or April forwarded a request, through Baring Brothers & Co., to be heard upon the subject at the War Office, and it was there early in May that I opened my plans to Captain Lefroy, to whom I had been officially referred. From him I learned that his friend, Captain Blakely, — whom, however, he did not then name to me, — was upon a similar plan of construction; and very soon after you called upon me with a letter of introduction from Captain Lefroy.

At this interview I stated, according to my original conception, that the ratio of resistance would be in the inverse ratio of the diameter *plus* a quantity derived from the diminution of the thickness. This plus quantity will, as you will perceive, just make up the difference between the simple inverse ratio and the inverse square; and I stated to you at the time that this might be the case, though I did not demonstrate it. You thought it would not. The difference between us then was rather one of form than of substance. You said it must be as the *inverse square;* and it was then and will be hereafter my belief, unless you say to the contrary, that you had come to this estimate of the subject from your own original investigation, without having seen Barlow's previous demonstration; for when I first mentioned Barlow's paper, and told where it could be found, you did not seem to be aware of its existence. I had forgotten the substance of it, and did not see it myself in London, nor afterwards, until after I had made the demonstration and illustration in my memoir.

Thus, you see, I wish you to take the credit which I think belongs to you, of being an original discoverer of the principle as much as Barlow, and, shall I say, myself, although he was first in point of time by some years. And if this statement will be of any use to you in your controversy at the War Office, pray use it there. . . .

DANIEL TREADWELL.

In July, 1852, the American Academy of Arts and Sciences, in order to raise funds to defray the expense of their forthcoming publications, voted to request several gentlemen, members of the Academy, to deliver each one lecture during the ensuing winter on subjects agreeable to themselves. The committee who had charge of this arrangement, addressing Mr. Treadwell, "express their confident hope that you will give them early notice of your consent to render this valuable service to the Academy."

In responding to this call, Mr. Treadwell took for his subject "The Relations of Science to the Useful Arts." The following abstract indicates his method of treating it: —

The superior excellence of the ancients in the "fine arts" he fully acknowledges; "the higher genius which has impressed itself upon the stone remains still above modern reach." But, on the other hand, there was among the Romans an entire absence of inorganic power in giving motion to the instruments by which all the operations of the useful arts are performed. They were without a water-wheel till the time of Augustus, and had no wind-mill till brought into Europe by the Crusaders in the eleventh century. The grain for bread was generally ground by men for a century later than Augustus, as fully proved by the numerous hand-mills discovered in the ruins of Pompeii. Iron and steel were known; but the most singular defect of the ancients in metallurgy was their ignorance of the uses to which cast iron may be applied.

"Why," says Professor Treadwell, "did not the Greeks or the Romans invent the steam-engine or the spinning frame? They had Socrates, Plato, Seneca, and many metaphysicians and moralists. . . . But it is impossible to avoid the conclusion that the improvement of the useful arts has never at any time been the vocation of the philosophers. . . . But, luckily for us, the wisdom of the ancient world was not confined to the philosophers; there were other men free to follow the devices of their genius. It is written upon the whole face of Greece and of the Empire in the magnificent hieroglyphics, formed by temples, aqueducts, roads, and bridges, that Pericles, Flaminius, Agrippa, and Trajan would have beheld not without emotions of admiration and delight a steamer breasting the Atlantic, a train flying across the Connecticut, or a whole people, from Louisiana to Maine, receiving together as one man words as they once fell from the lips of the great statesmen in Washington. . . . To Galileo belongs the merit of building up that system of experimental inquiry, the common sense system of investigation, which is the foundation of the inductive philosophy. . . . Bacon, nearly contemporary with Galileo in birth, but subsequent to him as a writer, an admirer of the useful arts, perceived, perhaps more vividly than any man of his class or time, the great power that mankind might attain over nature by the successful cultivation of the arts, and he gave utterance to his perceptions in language that no other man of his time save one could use. But this is by no means a merit sufficient to warrant the mighty reputation that has been assigned to him; and this reputation rests mainly, not upon the ground that he was a patron, eulogist, or admirer of the arts, but that he was what he distinctly claimed to be, namely, an inventor of a new art of inventing them. He fully expounded his system of invention as resting upon three things: first, upon experiment by which facts were to be collected; second, the subjecting of these facts to an examination by an elaborate mental process, which he details at great length; by this induction we were to arrive at the third, or last, matter of the system, namely, a discovery of the *forms* or *essences* of all bodies.

"But is there in these three great constituents of the system proper, the experiment, the induction, or the conclusion, one or all, that should give Bacon his worship? First, for the experiment; leaving out all reference to the priority of Galileo, when was the time that man did not depend upon experiment for his knowledge? Before Bacon taught him otherwise, it is said that man rested entirely, for what he knew, upon dialectics and logic. As though there was no knowledge out of the schools! Were the Pyramids reared and edified by logic? Did the Romans learn to subdue cities and build aqueducts by dialectics? Did the alchemists make their great discoveries without experiment? Why, one of these sages distilled over the same subject, spirits of wine, three hundred times, merely to see what it would come to at last. Was not this a patient interrogation of nature?

"Next, for the induction: it would be useless to say that Bacon ever examined an experiment, or the phenomena resulting from it, after the exact method pointed out by him. General principles and laws had been arrived at, by reasoning from particular instances, by civilized, and even barbarous men, in all ages. 'Without an experiment,' said Galileo to his opponents at Pisa, 'you could not tell that a stone thrown up would ever come down again.' The general truth had been discovered by the observation of a sufficient number of instances of falling stones. No better philosophical induction was ever made than that of Archimedes in the principle of specific gravity, from observing the diminished weight of his own body in water."

Lastly, for the character of the conclusion or object to be attained by the experiment and induction. Bacon supposed it would lay open to us the *essences* of bodies, that which makes heat heat, color color, hardness hardness; and knowing these, we should be able to make, by transmutation, gold, silver, or any other simple body. Indeed, he gives directions at length for making silver, not being quite certain that he had yet attained the exact knowledge of making gold. "Now it is not necessary to remind you that no such knowledge as this has ever been attained by man. We cannot say that it will not be, but can only say that in all that has been accumulated in knowledge we do not perceive that we are a single step nearer to it than we were at the beginning." *

"How does the case stand, then, between Bacon and the inductive philosophy? First, for the experiment. No one can successfully dispute that this has been the great teacher since man had a place upon the globe; and for any claim to an improved mode in the practice of experimenting, Bacon was wholly ignorant of all practice. However stained with gold, his hands were innocent of oil and charcoal; presenting in this a strong contrast with Galileo, who was not only the first philosopher, but the best experimenter and handicraftsman in Europe. Next, for the induction. It cannot be denied that general truths or principles were learned from particular instances ever since particular instances were observed; and for the particular method of mental examination which Bacon taught, no one does now or ever did follow it. Lastly, for the knowledge to be obtained or the object of the induction. That proposed by Bacon as the end of his inquiries never has been attained or generally sought for by the true followers of the inductive method. I cannot avoid the conclusion that to call the inductive philosophy after the name of Bacon is a misnomer as great as that made by calling this continent after the name of Americus Vespucius, and one of the same kind; and that Galileo was as much the leader and teacher of the inductive philosophy, in its systematic form, and in all that in which it differed from preceding systems, as Columbus was the discoverer of America."

There is an opinion very widely spread amongst certain classes that great improvements in the arts may be directly deduced from scientific knowledge without anything like a creative effort; and that the production of a great invention necessarily implies an acquaintance with all the principles and laws by which it acts. "This opinion does not appear to be well founded. The common pump furnishes an apt example; it was invented before the Christian era, but it was not until nearly two thousand years after its invention that Torricelli discovered and taught the scientific principles on which it operated; namely, that the water is made to rise in it by atmospheric pressure. The groined vaults of the cathedrals and other great buildings of Europe, elevated upon their slender columns almost to the clouds, were constructed by men unacquainted with the refinements of geometry or the application of its principles to the equilibrium of arches, and from no light but that furnished by their own genius and *tact*."

"But the strongest and most direct instance of the application of science to the arts is fur-

---

* The following from a paper by Professor T. H. Huxley, written thirty-five years after Professor Treadwell's lecture, is so strikingly in accordance with his views that it may be cited: —

"In our own country, Francis Bacon had essayed to sum up the past of physical science, and to indicate the path which it must follow if its great destinies were to be fulfilled. And though the attempt was just such a magnificent failure as might have been expected from a man of great endowments, who was so singularly devoid of scientific insight that he could not understand the value of the work already achieved by the true instaurators of physical science; yet the majestic eloquence and the fervid vaticinations of one who was conspicuous alike by the greatness of his rise and the depth of his fall drew the attention of all the world to the 'new birth of Time.'

"But it is not easy to discover satisfactory evidence that the 'Novum Organum' had any direct beneficial influence on the advancement of natural knowledge. No delusion is greater than the notion that method and industry can make up for lack of mother-wit, either in science or in practical life; and it is strange that, with his knowledge of mankind, Bacon should have dreamed that his, or any other, 'via inveniendi scientias' would 'level men's wits,' and leave little scope for that inborn capacity which is called genius. As a matter of fact, Bacon's 'via' has proved hopelessly impracticable; while the 'anticipation of nature' by the invention of hypotheses, based on incomplete inductions, which he specially condemns, has proved itself to be a most efficient, indeed an indispensable, instrument of scientific progress. Finally, that transcendental alchemy, — the superinducement of new forms of matter, — which Bacon declares to be the supreme aim of science, has been wholly ignored by those who have created the physical knowledge of the present day." — Professor Huxley, in "The Reign of Queen Victoria," Vol. II. p. 325, London, 1887.

nished by navigation. In determining the place of a ship on the broad ocean, genius, skill, and experience alone are nothing, and the observation of the compass and of the heavens would be unavailing, but for the deductions which science makes from them. In most other instances, the end is only wrought through the intervention of some species of machinery; here the observations being furnished, the sciences of geometry and numbers themselves become instruments by the operation of which the required object is produced. This is to be regarded, however, as almost a solitary or exceptional instance; and I must declare that, after an examination of many years, I have been unable to perceive that the arts have been advanced so exclusively by the application of science to their machinery or processes as is generally believed. Generally the great improvements in the arts have been made by men who were hardly acquainted with the rudiments of science. Still, however, they were all under the influence of the knowledge of the age, and received aid from their acquaintance with facts which had been disclosed by scientific investigation. This knowledge was highly useful in the perfection of the steam-engine and the chronometer: perhaps it was indispensable to give these machines that high degree of perfection that they now possess. It is true that this knowledge alone could never have invented a steam-engine nor a chronometer. To do this it was necessary that knowledge should be at the disposal of an imagination which could create and combine shapes never before seen, and trace the course of motion through series of bodies never before combined. The peculiar combination of qualities, intellectual and moral, necessary to give effect to scientific knowledge, so far as this is required to produce the great practical results witnessed within the last hundred years, is a combination of clear and active perceptive faculties, high imaginative power, a great faculty of comparison, and a determined will with never-tiring perseverance." *

This lecture was printed in 1855. President Quincy (then nearly eighty-four years old) thus acknowledges its reception: —

To Daniel Treadwell.

Quincy, October 12, 1855.

Sir, — I thank you for your lecture on the improvements in the useful arts, and their dependence upon physical science. I have read it with the attention the subject and everything from your pen naturally commands. The entire absence in ancient times of inorganic power in giving motion to the instruments by which all the operations of these arts are performed, was never before so strongly presented to my mind. A new train of thought was also presented to it by your vindication of the Gothic age from the popular opinion that it had lost, with Roman learning, the arts which had flourished during that period. Your tribute to the mediæval period for its aid to modern civilization seemed to me true and well deserved.

The spirit also with which you have stripped the metaphysicians, moralists, and philosophers, both of ancient and modern times, of the glory which an accident rather than a direct application of their minds to the subject has invested them, though bold, seems to be justified by history and fact. I never before had brought under my consideration the comparative merits of Galileo and Lord Bacon in the introduction of the inductive system of philosophy; but the priority of the former you have, I think, unequivocally substantiated. The claims of Lord Bacon I have long thought to be, on this subject, greatly overstated by his admirers, although I never before

---

* The title of the Rumford Professor adopted by the College is "Rumford Professor, and Lecturer on the Application of the Sciences to the Useful Arts." In accordance with the views expressed in this paper, Mr. Treadwell would have preferred "Lecturer on the Science of the Useful Arts."

saw them so thoroughly analyzed. There is a tendency of the human mind, which is almost universal, to exalt the *individual* and overlook *the time* and *the race.* Writers love to embody glory, and magnify their heroes at the expense of the species. The great improvements of the arts have been the gradual result of the improvable nature of mankind. At different periods of social progress men advance to a certain point, which necessarily includes or leads to the next stage in the advancement of the arts, which will unavoidably be reached. At this point some fortunate individual, whose thoughts have ripened and been at work, lights upon some master thought, which gives expansion and freedom to the flood which was behind him, by which he himself was driven to the happy occurring thought, the merit of which is his own, but no more. The real glory belongs to the time and the race, not to the individual. Contemporaries in obituary notices, biographies, and eulogies make everything of and attribute everything to the author of the lucky thought, and overlook the many and the period which gave him the power and aided him in attaining it. Experiment is the great schoolmaster, and he is and always has been abroad instructing the masses and instructed by them. The lucky individual who has first seized upon the master thought, like the general of an army, receives the whole glory of the victory, when in truth the common soldiers are the real conquerors. Among the causes which gave the impetus to the great improvements by which this nineteenth century has been distinguished, the principal has been, in my judgment, the American Revolution. The common mind of the time was set free to think, particularly in the United States, where the mind was not hampered by the prejudices and unwieldy habits of former ages. An example and a rivalry was communicated to Europe, the race thought and advanced together under a common sense of the value of experiment as the only path to advancement. An open field and fair competition have been the causes of the singular success in improving the useful arts which has distinguished the period.

But I must ask your pardon for the long yarn which I have unintentionally spun; but you must thank yourself, for you put my hand upon the distaff, I dare say without reflecting the aptitude of old men to be prosy and tedious.

Wishing you a long and happy life, with every element of inorganic matter to fill your sails, light your fires, and set your steam in motion, I am, as ever, truly yours.

JOSIAH QUINCY.

The following letters of Mr. Treadwell to various personal friends will be found interesting.

TO DR. WILLIAM SWEETSER.

CAMBRIDGE, October 19, 1846.

Dear Sweetser, — I heard through Dr. Parkman, a few days ago, that you were at Castleton. Indeed, I had concluded from my recollection of your engagements that you must be there at this time, and so I forward this to that place, in the hope that it will find you *comfortable.* How much does that word express, — all indeed that we can reasonably hope to obtain in life! We may now and then have a few hours of positive joyousness, counterbalanced by corresponding hours of absolute misery. But none ought to lay out for more than easy comfort, and this may be enjoyed without the risk which attends striving for a higher state of pleasurable sensations.

I have been in expectation of receiving a letter from you for some time. The last which I had was in July. You were then unwell, but recovering. You would, of course, have informed me if anything unusual had occurred, or if your health had not been re-established. I am desirous, however, of having evidence under your own hand that the world goes well with you, and write this rather to obtain an answer to that effect than to give you anything important of myself.

Still I must give in my account before I can ask you to render yours. First, then, this may be done in a few words. My health is better than it has been for some years, for which I most heartily thank God; whether he knows or cares about the thanks of such an insignificant atom is another thing. As to his having made any special interposition in my favor, I am not vain enough to believe it. But I have a feeling of gratitude that, in the order of nature, in my own organization I seem to be attaining a more sound state of health.

On looking over the above sentence, I doubt whether it is right, — whether my thanks or gratitude amount to anything like that deep feeling with which the heart is impressed toward another, who, we know, has labored for our benefit for the mere love of us. How difficult it is to read our own hearts, and how many, when they read their hearts aloud, read them falsely, although they suppose that God is hearing them!

I have spent the summer almost without occupation, having made two journeys to Connecticut River. At one of these, you will recollect, I proposed that you should join us. As it was, we had a most delightful time, and I should think that you must have enjoyed the season, the country, and the scenery, if you had been with us, and we should certainly have had pleasure in your company. Since our return we have gone to the old quarters at Sudbury almost every Saturday. Thus time has passed quietly, but I cannot say that it goes happily: the want of success in my guns leaves a mark which it will be hard to rub out.

Now, my old friend, will you not contrive to let us have a sight of you before long. I know that it will do us all good. Can you not take us on your return from Castleton for a few days? We have a room for you yet, whatever may happen from my diminished means hereafter.

Mrs. T. sends best regards. William Parsons is often out, and inquiring if I have heard from you.

Very truly and ever yours,

D. Treadwell.

To Dr. T. W. Parsons.

Rome, December 19, 1854.

Dear William, — I have received your four letters as they became due, and have to thank you very sincerely for thus keeping me so well up with what is passing about you. We left Florence the 3d of this month, and came by the Sienna road to Rome. At Sienna we were all waked up by an earthquake, which was the heaviest I ever felt; and many people in the city ran out into the streets, leaving their beds at midnight. But no harm was done, and the fine old tower of the Hôtel de Ville, or old palace, one of the highest and most striking in Italy, stood it without flinching. We were struck with the barrenness of the country on our route, but you know all this without my repeating it. We arrived at Dominic's hotel — Hôtel d'Amérique — on the evening of the 7th, and found Dominic, or Mr. Costanzi, the same obliging and gentlemanly person that he was in 1843, and his hotel excellent. I am afraid its situation in a confined street is rather against him. After a couple of days, Dr. Ware determined to take lodgings, which he found in Via Gregoriana. This was so far from us that I have been obliged, on account of Mrs. Treadwell and the females, to go nearer, and we are now — Mrs. T. and I — in fine rooms, No. 40 Via Gregoriana. This street is upon the Pincian Hill, just southeast of the Propaganda, and our front windows command a full view of St. Peter's, behind which we see the sun make his set.

The day after our arrival there was a great festa to promulgate the Pope's bull of the Immaculate Conception of the Virgin Mary, which was done at St. Peter's in presence of about fifty cardinals and some hundreds of bishops who had composed the council, and a throng that filled the cathedral. The reading of the bull was responded to by the cannon of St. Angelo, and the day closed with a complete illumination of St. Peter's, which is one of the greatest sights I ever saw, and has not been cried up above its merits.

Rome is very quiet. The French soldiers are said to be very much disliked; but it seems to me that they perform a necessary police service to a people that, without them, would run wild with political vagaries, to the destruction of all security of person or property. As to the Romans having a republic, they are about as fit for it as the Southern slaves are for freedom. Even Dominic gives up the "beautiful movement," and says, "It is impossible, they are not fit."

We have the news of the Crimea before you. The allies have had a hard time, but they have fought up to the standard of their blood, and as none but English and French can fight. I am sorry to see that so many in the United States take against them, as I believe this war was undertaken, at least on the part of Lord Aberdeen, in defence of national rights and in pursuance of the promise of treaties, and that it is substantially in favor of human progress and liberal institutions. My hope is that they will humble the Czar, support the Turkish independence, open the Black Sea to western commerce, and by this means bring the people upon its shores into a more civilized state, in the only way in which this end can be accomplished.

I must not forget to tell you that Robert and I went to Pisa, where all remains as we left it. The custode at the Cathedral recollected me as *le seigneur qui avec madame et un jeune monsieur mesurait la tour.* The old tower seems to lean more than ever. It is indeed a grand monument, and with the Cathedral, Baptistery, and Campo Santo is worth a long journey to see even a second time. Perhaps you will be glad to hear that in the "fraternizing" of 1848 the Florentines sent back that piece of chain they took from the Pisan harbor so many centuries ago, and it now hangs in the Campo Santo at Pisa, instead of the Baptistery of Florence. The Genoese still keep their piece of it. . . .

Daniel Treadwell.

To Dr. William Sweetser.

Paris, April 10, 1855.

My dear Dr. Sweetser, — If I am called upon in another world to answer for much misspent time in this, I am certain that no great part of it will be in useless letter-writing. Perhaps the great amount of time that I see others give in writing *nothings* in letters has given me a distaste for all labors of this sort, and thus I fail in my duty to let the few that I really like in the world hear from me, even when I have reason to believe that they desire it.

I need not write to you about Florence, Rome, or Naples, as you have seen them all so thoroughly, and moreover have Madam Starke on your desk. Let me tell you, however, that Italy has improved considerably since you were there; that is, it has taken more of an English or American aspect. There are fewer beggars, more work and thrift, and somewhat less dirt. Everything, politically, is quiet. The soldiers, French and Austrian, keep the peace in Lombardy, Tuscany, and Rome; and Naples takes care of itself, or is taken care of by the king; and it is best that it should be so, for the people are no more capable of governing themselves than the inhabitants of Bedlam are. Dr. Ware says that I have lost a great deal of *patriotism* since I left home. The truth is, that I see more clearly than he does the *compensations* in the systems of different countries. Here the armies, the priests, and the aristocrats are costly, and although they do some good, they do much harm. But we in America have, with our democratic freedom, great licentiousness, every kind of fraud in speculation, to a degree that no man knows when his property is secure, — a despotism of the masses, instead of the despotism of a gentleman. I am a republican, and prefer the American government to any other; but I greatly fear that we are becoming *demoralized* and disorganized, and I cannot say but I should like the government of Nero better than that of Robespierre and his cut-throat associates, although they were republicans. But enough of this.

Ever most heartily yours,
Daniel Treadwell.

To Dr. John Ware.

London, June 7, 1855.

Dear Doctor, — We are yet at 58 Margaret Street, and nothing worth noting has happened to us since you left. You are now, I hope, safe in Weston, instructing Mr. W. in the importance of the cultivation of colza. Don't be put down by any of his allusions to former failures in carrots. The great soul makes every failure the path to success, and the Sebastopol of carrots will be forgotten in the glorious Sea of Azof that shall be obtained from colza.

You of course had the news of the successes of the Allies, and have by this time got over your mourning for them (the successes). The English feel their triumph, and will not abate one inch of the terms of peace which were rejected by the Russians at Vienna. To these terms the Russians must come, and well will it be for the world if they accede in time, and before the Allies raise their demands.

I went to the House of Commons on Tuesday night, and heard a great debate, at which I sat from six to half-past twelve o'clock. I heard Cobden, Sir James Graham, Lord John (Russell), Disraeli, Mr. Bright, Lord Palmerston, and several small men. Upon the whole, my opinion of Parliamentary speaking was not elevated by the debate. Cobden, who was the first speaker after a whole week's adjournment of the debate for preparation, and who had evidently used the time in hunting up the subject, did not exhibit the kind of power that I had supposed him to possess, and which would seem necessary for a great popular agitator, — that which we call *stump oratory*. He stammered and hesitated a great deal, and after all did not find the choice words he seemed in search of. The House was very full, and evidently expected much from him; and though the after speeches were mainly in answer to him, he was reproached with not having shown the power once possessed by the leaders of the Corn Law League. Sir J. Graham and Lord J. Russell appeared to me to be about of equal ability. Fair, plain, sensible statements and reasoning were all that either exhibited, without anything approaching eloquence, or to those *feats of logic* that carry men even against their own instincts. But they gained upon the confidence of the House by showing themselves impressed with the interests of the state, as involved in the question, and not striving for themselves or their party alone. They both seemed like sensible men, wishing to do the best they could, each according to his own carefully considered course, for the interests of England. Disraeli presented a strong contrast to Sir James and Lord John in every point of character. He is a great master of words that flow in an easy stream, and amongst them many choice and appropriate ones, but you see in a few minutes that his whole object is to *damage* his opponents.

It is nothing to him beyond a mere pretence whether a measure is good or bad for the country, but whether he can persuade the House that the Minister is wrong, and that the only way is to turn him out, and give his place and his £5,000 to him, Disraeli. He is, you know, a Conservative, and highly in favor of carrying on the war, — the very opposite of Cobden and Bright in all his politics, and yet I dislike him more than any man in the House of Commons. He always makes me think of Mephistopheles, and I should like to have seen Lord Palmerston knock him down at the end of his speech on Tuesday night.

I never was more out in my life than in Mr. Bright, as I had supposed him in personal appearance compared with what I found him. He is put down in the list of members, "John Bright, cotton spinner, and a member of the Society of Friends." Of course I expected to see a tall, ungainly figure in a drab coat get up, with a broad brim hat on, and Thee and Thou the speaker through his nose. But instead of all this he turns out to be a stout, fine-looking man, with no mark upon his dress except a standing collar and a single-breasted coat, his cheeks covered with a most ferocious pair of whiskers. If old George Fox could see him he would say, "Thee a Quaker! thou abominable damned cheater!" He made but a short speech, but enough to show that he has great power, and must prove an *ugly customer.* Pope would perhaps take him as both Quaker and Presbyterian, as he is not only *sly* but *sour.* With him on one side, and Disraeli on the other, the Government have but a narrow path, and our hope must be, that, narrow as it is, it will lead directly to what the hack members call a safe and honorable and lasting peace.

I have read Flourens's[*] book attentively. It is not so much as I thought it would be. There is over pains taken to prove many things that are obvious in some cases, and in other cases general conclusions are drawn that are wholly unwarranted. Thus, at page 95 he says the period of gestation, of growth, and of the duration of life are all in proportion to each other. Now the gestation of man is three fourths of a year, of the horse one year. Man lives according to him 100 years, the horse 25 years; then we have, $\frac{3}{4} : 100 :: 1 : 25$; or, $18\frac{3}{4} = 100$. What confidence can we have in a man that will say this? I believe I do not misrepresent him, or mistake the meaning of his words.

We find everything very comfortable here. We live more to our minds than we did anywhere on the Continent, and we certainly have more that we like for the same money than we have had anywhere else. I should like to have the wine, the Falernian or Capri, but as yet I find no difficulty with the ale. I mean to be at home in season for a journey with you to Vermont, that we may compare our own country with this Old World, now that all is fresh in our minds; for although you and I have not much more to do with either, that is no reason why we should not make the most of them while they last to us.

I see that Governor Gardner has put down his foot against the removal of Judge Loring, but the "Know Nothings" seem to have it all their own way in many of the States. The Maine liquor law is making much talk here, and although there is no government in Europe strong enough to adopt and carry it out, yet the discussion will have a good effect in checking intemperance by public discussions and *moral suasion,* which must precede law everywhere, except, perhaps, in your beautiful Russia.

Pray let me have a long letter immediately on receipt of this, as I shall be here long enough for the return of the steamer, and I shall of course be anxious to know whether everything has broken up at home, and the despotism been established, before I venture to return.

With best remembrances of self and Mrs. T. to all, believe me ever yours,

DANIEL TREADWELL.

---

[*] De la Longévité Humaine et de la Quantité de Vie sur le Globe, par P. Flourens.

TO DR. WILLIAM SWEETSER.

CAMBRIDGE, June 26, 1856.

My dear Doctor Sweetser, — It gave me very great pleasure, a few days since, to receive your kind letter. My pleasure was greater as you did not absolutely owe it to me, I not having written since I received a note from you. I was, moreover, very glad to see the cheerful tone in which you wrote, not exultingly, as one overborne with good fortune, but as one calmly satisfied, or at least resigned, to the share of blessings assigned to him. Four years' work is ended, and you have returned to your family to take a little well-earned rest. I wish you to enjoy it with all my heart, and I only wish that you were so successful with the pecuniary results of your labors that you may be enabled to leave them when they shall become a burden and a *bore*, and enjoy without anxiety a healthful old age. I often recur to it as my misfortune that I am not nearer to you, and enabled to compare thoughts with you upon the great laws which hold all things in their grasp. I often think that you would share with me in conclusions, and go with me in the conception of truths that I am now obliged to ponder over alone.

Of all the men that I have known in life, you, Dr. Ware, and T. alone have I held to on terms of such entire confidence as to open and go through with a subject without some shadow of reserve. With poor T. it was but a reckless *abandon.* But it was pleasant, if not profitable. With Dr. Ware I have pursued many a sharp argument, and been righted on many nice points; but we always ended no nearer to agreement than we commenced. With you, on the contrary, I have found sympathy as well as aid in many a discussion "fit for reasoning man," and have always derived confidence in conclusions from the support of your authority. But where are you all now? T. away beyond the reach of a free interchange of ideas as they arise in frequent personal intercourse, and W. living in a constant combat with bodily infirmity, that takes away all the enthusiasm of his mind and a great portion of the enjoyment of life. My solitude has pressed upon me the more this past winter and spring from the deaths of Mr. Channing, Dr. Harris, and Judge Fay. With Channing and Harris I have been upon terms of pleasant intercourse for nearly twenty years, and with Judge Fay for nearly as long a period. I have had a great respect for him, as a high-minded and honorable man, and a great liking for him as a kind-hearted and pleasant companion. I say companion, for although some fifteen years my senior, this difference did not count in the character of our intercourse, as he was so young for his years that I always thought that he would outlive me. But I have seen him for the last time, and the parting with him has been a great grief to me. But sufficient for the day is the evil thereof, and I will hold you no longer in this melancholy strain. For after all life is not so bad as many accuse it of being. When I look round me, I am astonished at the number of things that I have to enjoy, and to occupy the consciousness of existence, the power of thought upon, to produce pleasurable feelings, or a sense of satisfaction; and it is the way for true wisdom to make the most of things within its reach, both in time and place, and, if there are some bitter viands upon the table of life, endeavor to pass them over in our feast, or, if they must be eaten, do it without making mouths at them. Will it not be possible for us to meet somewhere or somehow this summer? If we can contrive to do so, it will be a great pleasure to me. I suppose that you remain at Fort Washington for some two or three months. I wish you to let me know how long; and although I will not engage to do it, yet if I can see the way quite clear, and nothing occurs to prevent it, I may take a trip to New York for the sake of a day or two with you, not forgetting at the same time that you go through Boston without turning aside to see me. At any rate, write to me soon, as a letter is always welcome. Pray remember me to Mrs. Sweetser, and take for yourself and her the best regards of Mrs. Treadwell.

Ever truly yours,

DANIEL TREADWELL.

In 1856, Dr. William Johnson Walker, an eminent physician of Charlestown, and Thomas Lee, Esq., of Boston, made a joint gift to the President and Fellows of Harvard College of $10,000 each; the income from it to be for the benefit of Professor Jeffries Wyman, Hersey Professor of Anatomy, in acknowledgment of his many important contributions to science, and to enable him to continue his investigations. The following is Professor Treadwell's note of congratulation.

TO DR. JEFFRIES WYMAN.

CAMBRIDGE, October 19, 1856.

Dear Doctor Wyman, — I cannot forbear saying to you that I have heard, with the greatest pleasure, of the late donations to the College, made in terms so honorable and beneficial to you personally. You will permit me to say, here, what I have sometimes hinted to you, that I have often feared that your determined course of leaving your success entirely upon the merits of your purely scientific efforts, unaided by the arts which so many employ to obtain popularity, would not bring you to the standing which I knew that you deserved. But I am truly gratified in finding myself mistaken in my fears, and I think better of the discrimination of the public since finding my mistake. I can only hope that your case will not prove a lucky accident, but that many like you hereafter will find themselves encouraged and rewarded in following a like course. Then indeed will the true men be spared many a degradation and many a disgust that they would otherwise be obliged to endure in silence.

Believe me ever most sincerely yours,
DANIEL TREADWELL.

TO DR. WILLIAM SWEETSER.

CAMBRIDGE, January 8, 1857.

Dear Sweetser, — Although I have nothing to write, yet I cannot let go by the addition of another unit to the year of our Lord without wishing that it may prove to you and Mrs. Sweetser a happy one, 1857. I little thought fifty years ago that I should be alive to make this a true date. But so it is, and I am not without hopes that I may yet add another ten to it. If so, I trust that you will be here to see.

Nothing really has turned up with us. We are all quieted down since the election, and accept Buchanan as we should if he had been made for it. Of deaths, we have had none that you will think of a second time but that of Francis C. Gray. He left some sixty thousand dollars, and a most splendid collection of engravings, to the College. Mr. Ebenezer Francis, *the rich man*, it is said, will not live the year out, as he is breaking under the weight of eighty-one years.

In the matter of health, I have been remarkably hearty since say the middle of October. That pull down in New York seems to have been followed by a strong reaction, for which I trust I am duly grateful.

Lastly, and I put it last that you may remember it best, for the visit from Mrs. Sweetser and you that you engaged for when we were at your house. I shall leave the time altogether with you, provided you put it within a reasonable time, and give us a good length of it when you come. You will go to Brunswick in a few weeks, and I hope and trust that, even if Mrs. S. does not come with you then, you will not fail to stop a day or two with us. But nothing would give Mrs. Treadwell and myself more pleasure than to have Mrs. Sweetser come on then with you, and stay all the time that you are at Brunswick. But as I said before, make the time when you see fit; we shall only insist on what you bargained for, namely, a long visit and at an early period. . . .

I am, and have been for a few weeks, reading and mastering Bishop Berkeley's theory of the non-existence of the material world. It has been a bother to me all my life, but I have now mastered the conception of it, and am well repaid for my labor. I think it is all wrong, and do not believe that he believed in it. But it is wonderfully ingenious and supported with vast ability. Mrs. T.'s best regards to you, and those of both of us to Mrs. Sweetser.

Ever truly yours,
DANIEL TREADWELL.

The following communication to the Boston Society of Natural History well illustrates Mr. Treadwell's habits of observation, and his patient and carefully conducted experimentation in a matter so far removed from his ordinary pursuits. His reflections and their practical application are well worthy of note.

The partial report printed in the proceedings of the Society was also printed in Samuel's "Book of Birds."

On the Food of the American Robin. (*Turdus migratorius*, Linn.)

On the 5th of June, 1858, when driving in the vicinity of Fresh Pond, my attention was attracted by two young robins which had probably been turned out of their nest by some mischievous boy or cat. They were running rapidly by the roadside, uttering loud cries of distress. As they could not raise themselves upon the wing, I had no difficulty in taking them both. They were quite young; their tail feathers being less than one inch long, and, as I inferred from the actual weight of one of them a few days after, I think they then weighed about 25 or 26 pennyweights each, — less than half the weight of a full-grown robin; but they were plump and vigorous. As it was evident that they would soon perish if left to their own resources, I determined to take them home and give them a chance for their lives in a cage, for a while at least, thus repaying as well as I could the obligation which two of their namesakes, if not their blood relations, conferred upon the "children in the wood" in another place, and many years ago. Having with some trouble provided a temporary cage, I commenced feeding them with earth-worms, giving three (I have taken their weight at 12 grains each in the accompanying table) to each bird, it being then near sunset. During the second day I gave them 10 worms each, which they ate ravenously. Thinking this must be much beyond the quantity of food that could be supplied by the parents in the wild state, I cut them off with this allowance. On the third day I increased their food in the forenoon to 8 worms each, but in the afternoon I found that one of the birds was becoming feeble, and it soon refused its food and died. On opening it, I found its crop, gizzard, and whole intestine entirely empty, and I therefore concluded that it had perished for want of sufficient food; the effect of hunger being perhaps increased by cold, as the thermometer was but about 60°. I therefore placed the other bird, which yet seemed vigorous, in a warmer place, and increased its food, giving it in the whole day 15 worms. The fourth day this was increased to 24 worms, on the fifth to 25, sixth to 30, and on the seventh to 31; but as the cry was still for more, and as the bird seemed to be losing plumpness and weight, I commenced weighing both the bird and his food. The following table exhibits the amount of food consumed each day for thirty-two days, and the weight of the bird each day after the seventh day. The weight of the bird on the first day was, as I have said, inferred from its subsequent weight. The worms were not actually weighed after the twelfth day, for, as I found by numerous trials that those of medium size, and such alone were given, weighed from 11 to 15 grains when freed from dirt externally, I have entered them at 12 grains each in the table. On the fifteenth day I tried a small quantity of meat, and finding this readily eaten, I increased it gradually, to the exclusion of the earth-worms. With the meat the bird ate a large quantity of earth and gravel, and always drank freely after eating. Considering this meat clear muscular flesh, both in its effect upon the appetite and nutrition, as equal to twice its weight of earth-worms, I have given it that value in the sixth column, which I intend to represent the value of the whole amount of food taken in weight of earth-worms.

Day.	Number of Worms	Weight of Worms, in Pennyweights.	Other Food.	Weight.	Equivalent of all Food in Worms.	Weight of Bird. Dwt.			Day.	Number of Worms.	Weight of Worms, in Pennyweights.	Other Food.	Weight.	Equivalent of all Food in Worms.	Weight of Bird. Dwt.			Remarks.
						Morning.	Noon.	Evening.							Morning.	Noon.	Evening.	
1	3	1½	. .	. .	1½	. .	. .	. .	17	67	33½	. .	. .	33½	32	. .	35	. . . .
2	10	5	. .	. .	5	. .	. .	. .	18	71	35½	. .	. .	35½	32	. .	35	. . . .
3	15	7½	. .	. .	7½	. .	. .	. .	19	32	16	Beef	10	36	32½	. .	35½	Eats much earth.
4	24	12	. .	. .	12	. .	. .	. .	20	4	2	"	22	46	. .	. .	40	Drinks after food.
5	25	12½	. .	. .	12½	. .	. .	. .	21	8	4	"	14	32	35	. .	36	. . . .
6	30	15	. .	. .	15	. .	. .	. .	22	4	2	"	21½	45	. .	. .	42	. . . .
7	31	15½	. .	. .	. .	. .	23	. .	23	0	0	"	21	42	. .	. .	46	. . . .
8	30	15	. .	. .	. .	. .	23	. .	24	2	1	"	18	37	. .	. .	46½	. . . .
9	33	16½	. .	. .	. .	23	. .	24	25	0	0	"	17	34	. .	. .	. .	. . . .
10	32	16	. .	. .	. .	22	. .	24	26	4	2	"	18	38	. .	. .	51½	3 cherries.
11	40	20	. .	. .	. .	21	. .	26	27	0	0	"	23	46	. .	. .	52	. . . .
12	52	26	. .	. .	. .	23	. .	25	28	6	3	"	16½	36	. .	. .	. .	6 strawberries.
13	61	30½	. .	. .	. .	23	. .	27	29	0	0	"	18	36	. .	. .	55	. . . .
14	68	34	. .	..	. .	24	. .	29	30	6	3	"	15	33	. .	. .	. .	Bread.
15	62	31	Beef	2	35	27	. .	32	31	6	3	"	15	33	. .	. .	55½	Bread ; rice.
16	56	28	"	4½	37	30½	. .	34	32	0	0	"	17	34	. .	. .	. .	4 strawberries; bread.

By this table it will be seen that, although the food was increased up to 40 worms, weighing 20 pennyweights, on the eleventh day, the bird rather fell off than increased in weight, and it was not till the fourteenth day, when he ate 68 worms weighing 34 pennyweights, that he began decidedly to increase. The weight of the bird on the morning of this great feat of gormandizing was 24 pennyweights; he therefore ate 40 per cent more than his own weight in twelve hours, and when he had finished weighed 5 pennyweights, or 15 per cent, less than the food he had taken in that time. The length of these worms, if laid end to end, would be about 12 feet, or about ten times the length of the intestine into which they ultimately passed. Will it be said that the earth-worm contains but a small amount of solid or nutritious matter? Let us then take the twenty-seventh day, when the food was exclusively clear muscular flesh, beef, and the quantity 23 pennyweights. The weight of the bird is not given in the table for the morning, but at night it was 52 pennyweights, or but little more than double the actual amount of muscular flesh consumed during the day, not to notice the water and earth. What a wonderful contrast does this present with the amount of food required, not merely with the cold-blooded vertebrates, fishes, and reptiles, many of which can live for months without food to be seen, but with the mammalia also! A man at this rate should eat about 70 pounds of flesh a day, and although this is not entered in the table, to equal the bird he should drink some 8 or 10 gallons of water.

Can it be that all this food is required to maintain the temperature of the bird some six or eight degrees above the standard of the mammalia? Or are the powers of life, the muscular and nervous energies, and the processes of assimilation and absorption, so much more exalted in birds than in men and beasts? These are questions naturally suggested by the subject, but not to be answered, by me at least. Another question that yet more immediately presents itself is this: How can this immense amount of food required by the young birds be supplied by the parents? Suppose a pair of old robins with the usual number of four young to a brood. Their young would require, according to this instance, 250 earth-worms, or their equivalent in insects or other food, a day. Suppose the parents to work 10 hours, or 600 minutes, to procure this food. This would be a worm in every $2\frac{4}{10}$ minutes, or each parent must procure a worm or its equivalent in less than 5 minutes during 10 hours, and this in addition to the food required for its own support. I know that the industry of birds in procuring food for their young has often been noticed; but I know of nothing equal to the above requirement. I have had three pairs of robins that have raised each pair its brood upon trees within twenty yards of my house during the present season, and I have observed them often; but I never saw them return to their nests with supplies oftener than once in ten minutes, although they worked with great industry. Notwithstanding all this, the young, four in each brood, were raised successfully, however irreconcilable it might seem with what I might have predicted from the quantity of food required by the bird raised by me.

It might be seen that my table of experiments ends with the thirty-second day. The bird had then attained his full size, and was intrusted to the care of a faithful person during my absence on a journey. On my return, after eighteen days, I found it strong and healthy, with no increase of weight, though its feathers had grown longer and smoother. Its food had been weighed daily and averaged 15 pennyweights of meat, beef, veal, or lamb, 2 or 3 earth-worms, and a small quantity of bread each day, the whole equal to 18 pennyweights of beef, or 36 pennyweights of earth-worms, and it has continued to eat this amount daily to the present time. I at first attributed the great consumption of food by this bird to the unnatural condition in which it was placed, being in a constant state of excitement very different from the quiet of its nest; but as it has continued in its confinement, certainly with much less exercise than is taken in the wild state, to eat one third of its weight of clean flesh daily, I concluded that the food that it consumed when young was not much more than must always be provided by the parents of wild birds.

If you find in the preceding narrative no addition to your previous knowledge, and nothing to interest you as a technical naturalist, I think that you will agree with me that every arborist and every admirer of trees may derive from it a lesson showing the immense power of birds to destroy the insects by which our trees — especially our apple trees, elms, and lindens — are every few years stripped of their foliage, and often many of them entirely killed. The food of the robin while with us consists principally of earth-worms, various insects, their larvæ and eggs, and a few cherries. Of earth-worms and cherries they can get but few, and those during but a short period, and they are obliged therefore to subsist principally upon canker-worms, some kinds of caterpillars, and bugs, the great destroyers of foliage. Now if each robin, old and young, requires for his daily subsistence and growth an amount of these equal to the weight of earth-worms required by my young bird, what prodigious havoc must be made by a few hundreds of them even upon the insects of the largest orchard or the elms of a whole park. Is it not then a most advantageous bargain to us to purchase this service of the robins at the price of a few cherries? There has been a great improvement in this matter of preserving birds since my remembrance, and, with a little more attention to the subject, I have no doubt but we might produce such an increase as would save ourselves from the labor required for the appliance of tar and oil and zinc plate, and all other methods by which we seek, though with very imperfect success, to destroy our mischievous insects.

To Professor Daniel Treadwell.

Boston, September 18, 1858.

Dear Sir, — At the first September meeting of the Boston Society of Natural History, the Society was greatly entertained and instructed by a communication on the food of the American robin, from yourself. I am desired to communicate to you the thanks of the Society for your valuable paper, in accordance with a unanimous vote passed on that occasion.

I remain, sir, with great respect, your obedient servant,
S. L. Abbot, *Corresponding Secretary.*

To Dr. William Sweetser.

Cambridge, January 1, 1860.

My dear Sweetser, — Never did I expect (but a few years ago) to make it a date, and yet there it is. It is upon us, not only a new year, but a new decade, and the last I shall ever shake hands with. It behooves me, therefore, to make the best possible use of it, and get as much innocent enjoyment out of it as I may; and you have aided me in this by the very kind letter that you have just sent me, and which I take in the light of a most acceptable new year's present.

First, it gives me great pleasure to see that you and Mrs. Sweetser are passing on in such a comfortable, quiet, healthful way together. Whatever you may say about "life being hardly worth the possession," there are *spots* of it when it is a great good, and the consciousness of enjoyment is worth taking great pains to attain. At any rate, I am willing to hold on at present, and I hope you will stop and keep me company. I would that you were a little nearer, that we might exchange fresh thoughts without this artifice of writing, to which I have a constitutional antipathy. . . .

I am now reading a book that I think will make as great a noise as that made a few years ago by the "Vestiges of Creation." It is "On the Origin of Species by Means of Natural Selection, etc.," by Charles Darwin, M. A. Mr. Darwin is a correspondent of my friend, Dr. Gray, and Gray says — as indeed his book bears witness — that he is a very thorough naturalist, having been devoted to the study, under the most favorable circumstances, in London, for many years, during many of the last of which he has been elaborating his theory by experiments on plants and animals, and collecting information by correspondence with naturalists everywhere. The result is this book of about five hundred pages, as the precursor of a more complete treatise. I have not yet finished the present volume, but as far as I have read it seems to me a very able work in support of the "Development Theory." Many of his views are quite new to me, and indeed he claims for them the honors of a discovery as *his theory*. He will certainly succeed in setting *afloat* the old "Plan of Creation" in the organic world, if he does not destroy it. The tendency of the work is most decidedly *atheistical*, or *pantheistical*. I hope and trust that it will be searchingly reviewed by some great and *broad* naturalist, for in this way only can we expect any approach to truth from the conflict. If the *little priests* will let it alone, I shall be glad. A good American edition is promised in a fortnight. You cannot fail to find in it matter for many an hour's cogitation.

Ever truly yours,

DANIEL TREADWELL.

Soon after this letter to Dr. Sweetser, Mr. Treadwell took part with his friend, Dr. Asa Gray, in a discussion of Darwin's treatise on the "Origin of Species," upon its natural theology, and its influence upon the argument from design: "Is Darwin's Theory Atheistic or Pantheistic?" It was first printed in the American Journal of Science and Arts, September, 1860, and again by Dr. Gray in his "Darwiniana," in 1876.

TO PHINEAS DOW, ESQ.

CAMBRIDGE, June 11, 1861.

Much respected old Friend, — I have received your letter of the 6th instant, and am most sincerely grieved at the accumulation of misfortunes that have gathered upon you during the last year. It seems hard indeed that, after so many years honestly devoted to an honorable employment, with temperance and frugality, you should find yourself, in your age, pressed with poverty in addition to the great affliction of the loss of your good and faithful wife. Words are nothing, but I cannot forbear assuring you that I feel very deeply for you in this your time of great trouble.

I wish it were in my power to do something more for your help than this letter contains, but my income is not large, and the present unhappy condition of the country makes it now quite precarious. As it is, however, I send you a draft for forty dollars, which I beg you to accept, and hope it will give you some relief. Please to write to me immediately, that I may know that the draft has reached you, and write to me again a month or two hence, that I may know how fortune is then dealing with you. For myself, I am in feeble health, and see that the end is not far from me.

With the most sincere hope that you may yet have brighter days, I am, most sincerely, your friend,

DANIEL TREADWELL.

TO DR. WILLIAM SWEETSER.

CAMBRIDGE, July 29, 1861.

My dear Sweetser, — I found your kind letter on my return to Cambridge from Hingham (the Old Colony House), where I have been for the last three weeks with Mrs. T., endeavoring to pick up a little more life. The truth is, that I have been rather drooping for most of the time since you were here in spring, and having lost my old resort of Sudbury, — for poor Mr. Howe is dead, and his family of one hundred and twenty years' standing become extinguished, *all gone* (it makes me sad to write it), — I have been obliged to seek out new quarters. My stay at Hingham was quite pleasant, the rides on the sea-shore and about the country very fine, and Mrs. T. and myself have both improved in health; but we did not like the gay company with which the hotel is filled, and concluded to return home for a few days, and then seek some inland place, about which we can pass the heats of August.

For me, I have but little to look to but to eke out my short *remnant* in the most comfortable way. I shall now most likely reach the seventieth milestone, as it is in plain sight, and all that is beyond that "threescore and ten" is, according to the Psalmist, as translated by Dr. Watts, "sorrow, toil, and pain." Well, I hope not, "but what must be will be." I am greatly obliged to you for your pressing invitation to us to make you a visit. The truth is, I have been thinking of it, and hoping that Mrs. T. would be well enough to enable us to accomplish it for several months past; and now, without promising to do it, I *lay out*, after the hot weather is over, say about the 1st of September, to take the steamer to New York, and, after resting a night or two in the city, go out and have a day or two with you and Mrs. Sweetser. But I will see, and of course write to you again about it when the time comes. You see that I have thus far filled my letter all about "I, me, and us." Now for you and Mrs. Sweetser. It gives me great pleasure to see, from the tone of your letter, that you are about as happy as one ought to expect to be. With good health, a pleasant retirement, and, if without great riches, without any pressing anxiety for being assured the comforts of life, what more, but a philosophical spirit, which you have, can you desire? *Jupiter reigneth*, and will take care of all as he must.

I hope you will not *worry* yourself about the war, and what is to come out of it. I finished my lamentations for the country months, if not years ago. We have been going in political demoralization and corruption for forty or fifty years, and now the end cometh. Sooner indeed than I expected, but I have always said it could not be very far off. Great communities must have masters other than the people, and we are but going over the old story, — liberty, corruption, anarchy, despotism. We are now passing from the second into the third stage of our progress. You seem to be out of temper with the South, or the Southern demagogues. Rascals, you call them. Perhaps, if a trial were made for showing the greatest number of rascals, we could beat them all hollow. This state of things was, in my mind, brought on by the Abolitionists (and I look upon all, or almost all, the Republicans, here in Massachusetts at least, as Abolitionists in substance) more than by the Carolinians. We threw the first stone at the Constitution. But mad, mad, is the word for both sides, and by this the country is divided, and never to be joined again. Mr. Longfellow is recovering from his severe burns, but Cambridge yet shudders at the thought of the poor lady.

My very best regards to Mrs. Sweetser, and Mrs. Treadwell's to both of you. I remain ever faithfully yours,

Daniel Treadwell.

To Dr. William Sweetser.

Cambridge, January 25, 1862.

My dear old Friend, — I have suffered a great deal for some time from the reproaches of my conscience for having neglected to write to you, and thank you most sincerely for not reproaching me for it in your letter that I received yesterday. I could not have blamed you if you had given me a sound scolding for my most ungrateful neglect. But I assure you that, if I have failed to write, and said to myself to-morrow and to-morrow, I have not failed to think of you very often, and always with the best wishes and hopes for your continued life, health, and happiness. For you alone are now about the only man "under the wide canopy of heaven," as Homer says, that I think cares *much* about me, or perhaps I ought to say most about me. It was therefore a great pleasure to me to find, as I did by your letter, that you are well, and enjoying life in the same quiet way that you were in at our most pleasant visit last autumn. For me and Mrs. Treadwell we have been, since then, in our usual uncertain health. I was much down soon after my return from New York, but I have got over it, and for the last three months have been remarkably well, spirited, and active. I have employed some time in revising, *perfecting*, and publishing a paper that I read, in substance, to the American Academy many years ago. It is short, but *I think there is much in it.* I shall send a copy per mail with this; and if you will read it, so as to get hold of it, I think you will like it.

I have, likewise, taken up my *cannon* again. This must now come up, and I have written upon it to the authorities at Washington, and shall, during the present week, publish a pamphlet upon it. This I will send you as soon as it is out. I think you will say it ought to have had the motto, "Who would have thought the old man to have had so much blood in him?" But we shall see what comes of it. One thing is certain, I shall not "worrit" about it.

For Mrs. Treadwell, she is about as she was when at your house. She often speaks of her visit as one of the most pleasant that she ever made. She had a letter from Mrs. Sweetser a few days ago, with which she was much pleased, and will answer it very soon. In the mean time, her love to both.

What a miserable business this taking of Mason and Slidell has turned out to be. What fools the politicians and lawyers have shown themselves, not to have known at once that it was entirely contrary to the law of nations, and that England would never put up with the insult and wrong. The truth is (and Mrs. Sweetser will agree with me if you do not) that we have had all our heads turned by a success through the greater part of the last eighty years. This has engendered such an overweening opinion of ourselves that we have thought we were a match for all the world, and Jupiter (the planet Jupiter) into the bargain; and now the time has come to pay for our nonsense. I do not see any way out of it. The Union split in two, and the Constitution gone! Alas for the great Republic! I have known this thirty years that it must come, but it has come at last "like a thief in the night," and after all taken me by surprise. But why should a man of seventy grieve for the few years that remain to him. Those that are coming forward in life will find some way to carry on the world that they will possess.

Best regards to Mrs. Sweetser, Mr. and Mrs. Haven, Mr. J. Haven, and Mrs. Hopkins, and believe me ever yours,

DANIEL TREADWELL.

In April, 1862, during the war of the Rebellion, the State of Massachusetts was in want of guns for the defence of her harbors, and applied to Mr. Treadwell to make them. A Commission was appointed, and an arrangement made by which he undertook to manufacture one hundred large guns according to his methods. The Commission, and a joint committee of the Legislature, after a full examination of the subject, made reports highly favorable to the guns, and recommended that they be adopted for arming the forts, and an appropriation be at once voted for the purpose. The appropriation failed, being lost in the Senate at its last reading on the last night of the session by a majority of one vote, — 18 to 17.

A few days after the failure of the appropriation, Governor Andrew sent to the Secretary of War the following letter, calling the attention of the Government to the importance of the propositions that Mr. Treadwell was about to make, and his ability to execute them.

To HON. EDWIN M. STANTON, *Secretary of War, Washington, D. C.*

COMMONWEALTH OF MASSACHUSETTS, EXECUTIVE DEPARTMENT,
BOSTON, May 7, 1862.

Sir, — Professor Treadwell, of Cambridge, Massachusetts, and Francis C. Lowell, Esq., of Boston, intend to invoke the attention of the Government of the United States to an invention of the former in heavy ordnance, which I think it is easy to prove of great value. It was my intention to have caused the manufacture of a quantity of the "Treadwell gun" under a resolve of the Legislature of Massachusetts; but, by some misunderstanding, the *appropriation* failed in the Senate on the last night of the session, although a resolve authorizing me to spend half a million of dollars for the purpose had passed with no serious opposition.

A very intelligent commission of four gentlemen, appointed for the purpose, had examined and reported on the Treadwell invention in the most satisfactory manner. Of the scientific attainments of Professor Treadwell, and of the high character of that gentleman and of Mr. Lowell, it would be superfluous to speak in Massachusetts. And I venture to urge that whatever attention you can pay to such a subject, if presented by any persons of eminent and unquestionable position as men of the highest honor and intelligence, should be accorded to these gentlemen and their errand.

If the army or navy would give the order for a certain quantity of Professor Treadwell's ordnance, it would secure the perfection and success of an invention which has already ceased to be merely experimental, and that too without risk to the Government.

It does not seem to require that any ordnance officer should be convinced in advance, since, unless the guns will stand the tests previously agreed upon, the parties contracting will not expect them to be taken. They only ask an order, with the understanding that the Government shall not receive and pay for the ordnance unless it proves capable of doing what is promised.

With the highest respect, I am your obedient servant,

JOHN A. ANDREW.

A duplicate was given, directed to Captain Fox, Assistant Secretary of the Navy.

Professor Treadwell was willing to undertake the manufacture of cannon of large calibre; but as he was not a founder, or gun-maker, he had no establishment for making these guns, and after the experience he had of the United States Government when making his wrought-iron guns, and the great losses he had been subjected to thereby, he did not think it advisable to put up the necessary machinery, and supply the necessary tools, in order to undertake a manufacture upon the uncertainty of bargaining with a single customer, not even the United States.

In June, 1862, the United States Government issued proposals for the manufacture of heavy guns. Anticipating this, Professor Treadwell had made the following proposals in advance.

TO THE HON. EDWIN M. STANTON, *Secretary of War.*

CAMBRIDGE, May, 1862.

Sir, — The improvement of ordnance by increasing it in strength and size has been the principal object of my labors and thought for more than twenty years. I have done this with great pecuniary loss, and against great discouragements. All this is well known to most of the officers of the ordnance of both services of the United States. It seems to me now, however, that if your Department will accord to me a contract or order for a number of guns such as are now constantly ordered from others, who are pursuing their business under the light which they have borrowed from my inventions, I may be put in the way of attaining my long-sought end, and without any extra expense or risk from experiment to the Government, put it in possession of better guns than are attainable by any other means. I therefore solicit an order for the three following kinds of guns: —

1st. For 50 of 7⅞ inches' calibre, to weigh say 9,000 pounds, and carry a rifled ball of 100 pounds. The guns to be covered for the space of 2½ feet between the breech and trunnions by wrought-iron hoops, or rings, "put on under great strain," in the manner invented by me, and since followed in England by Captain Blakely and in this country by Captain Parrott. The price of these guns to be eighteen cents a pound.

2d. For 30 of 9 inches' calibre, to weigh say 16,500 pounds, to carry a rifled ball of 184 pounds. To be hooped from the breech to one foot in front of the trunnions in two layers. The hoops to be put on as the above, and also secured to the gun and to each other by screw threads, as described in my patent. The trunnions to be formed upon one of the hoops. The price of these guns to be twenty-five cents a pound.

3d. For 20 of 10½ inches' calibre, to weigh say 27,000 pounds, and carry a rifled ball of 300 pounds; to be hooped like the preceding; the hoops [if desired] to be carried over the whole length of the gun. The price of these also to be twenty-five cents a pound.

The Government not to be bound to take any of the 100-pounders unless delivered within eighteen months; the 184-pounders, unless within twenty-seven months; the 300-pounders, unless within three years. But I should hope and expect to complete the order much within the above-specified times. My works and workmen, shop, and materials, to be at all times open to the inspection of a Government officer. The guns to be subjected to such proofs as may be agreed upon, and any question of the intent or understanding of the parties that may arise to be settled by reference.

My desire to obtain an order in the above form is not founded upon mere pecuniary interest, but to obtain for myself a mechanical success, and at the same time to put the Government in possession of the largest, strongest, and best possible gun in the shortest possible time.

Drawings of the two proposed modifications of my gun are herewith presented. They may be changed in any of their details to meet the wishes of the Department, if they do not interfere with the essential principle on which the improvement is founded.

DANIEL TREADWELL.

These propositions were referred to General Ripley of the Ordnance Department, who made the following report.

TO HON. EDWIN M. STANTON, *Secretary of War.*

ORDNANCE OFFICE, WASHINGTON, May 21, 1862.

Sir, — I have examined the propositions submitted by Mr. Treadwell, which you referred to this office, and now report, that the methods invented by Mr. Treadwell for the manufacture of cannon of large calibre were published by him several years since. His methods as now proposed may be briefly stated to consist in making the initial tube, which forms the bore and breech of the gun, in one piece of cast-iron, and then to strengthen the tube by covering it with successive hoops of wrought iron, screwed on under suitable tension. The hoops to cover a part or the whole length of the tube, and to consist of one or more layers over each other, as the size and strength of the gun may require.

This method of construction appears to promise a maximum strength with any given weight of material in as high a degree as any other method now known or practised. The most successful trials of projectiles recently made in England to penetrate iron targets were, according to newspaper reports, made with cannon constructed on similar principles, which tends to confirm Mr. Treadwell's theory. At the present time it is an object of great importance to artillerists to give the highest possible velocity to projectiles of great weight, in order to penetrate and destroy heavy iron-clad defences; and whatever means may be devised for giving greater strength and safety to large cannon will promote that object. Among all the numerous methods which have recently been suggested for improving large cannon, I have not seen any which appears better adapted to that purpose than those proposed by Mr. Treadwell. I am therefore of opinion that his invention is worthy of a trial.

His processes of manufacture are, however, very expensive, and cannon made as he proposes will cost much more than is now paid for any other large cannon of equal weight. His proposition to make one hundred guns of different sizes at the price named will, if accepted, require an expenditure of about $340,000. I think it would be inexpedient to make a contract involving so large an amount for any untried weapons, however confident may be the expectations of ultimate success. Before making any contract for a large quantity of new weapons, an actual trial of one or more of them should be made in connection with such others now in use as are designed for similar service; the trials to be so arranged as could demonstrate conclusively the relative merits or demerits of the new invention compared with models already in service. Whatever practical value the new invention might be found to possess, either in capacity for powerful work or for prolonged endurance, would thus be satisfactorily ascertained.

If it shall be decided to make a trial of Mr. Treadwell's cannon, I would suggest that one or two of large size, say of eight or ten inch bore and rifled, be ordered upon the condition, that, if on trial they proved to be satisfactory, they should be paid for at a stipulated price. And also, that the Department may then at its option order an additional number for service at prices not exceeding those stated in Mr. Treadwell's proposition.

Respectfully, I am your obedient servant,

JAMES W. RIPLEY, *Brigadier-General.*

The propositions were not accepted, and no further efforts were made.

In 1862, Captain Rodman of the Ordnance made a detailed report of the results of experiments conducted at the expense of the Government in favor of a gun of his own production. In this gun he restored the old method of casting upon a core, and passed through the axis of the core a stream of cold water, in order to produce a more perfect equilibrium among the particles of cast iron of which it was composed than they have when the cooling is from the outside surface only, as is the case with guns cast solid.

Mr. Treadwell demonstrated that the strength of such guns is by no means in proportion to the thickness of their walls; indeed, that the difficulty, if not the impossibility, of securing the proper equilibrium among the several theoretical layers of particles in the walls which were supposed to constitute in very large cannon *natural* hoops at different distances from the bore, may render very thick walls a cause of weakness instead of strength.* Mr. Treadwell's conclusions were subsequently fully sustained in practice.

Mr. Treadwell also pointed out a fallacy in Captain Rodman's estimate of the pressure on the walls of his gun by the fluid produced by fired gunpowder, as measured with an instrument of his invention. The instrument consists of a small, but strong iron frame, having a shank or plug forged upon one of its sides. This plug is one and a half inches in diameter, and one and a half inches long, and is formed into a screw, the thread of which corresponds with a similar screw-thread cut into the outer portion of each of several holes fourteen inches apart, extending from near the breech towards the muzzle. A small hole is bored through the axis of this plug, making a free passage to the calibre of the gun. A piston is nicely fitted to this hole in the plug, and thus the end of the piston, receiving the whole of the force of the fired gunpowder, will be driven outwards at each discharge. A large steel head or block is fitted upon the outer end of the piston, and from this head rises a lozenge-shaped point. Against this point, and firmly fixed in the frame, is a piece of thick copper, in which an indentation is made by the point at each discharge. The depth of this indentation is then compared with that made by a known pressure of weights made upon a similar tool, and from this comparison Captain Rodman infers the amount of the fluid pressure of the fired gunpowder on the walls of the cannon. Mr. Treadwell showed that the movable mass of matter composing the instrument was fired against or into the copper, as much as the ball is fired out of the muzzle of the gun. The pressure to which the instrument is subjected changes its inertia into living force, and causes it to display and register double the force which is applied to it.

"Captain Rodman seems, indeed," says Mr. Treadwell, "to have had no suspicion of any error when his instrument gave indications of a force wholly incompatible with the

---

* "On the Practicability of constructing Cannon of Great Calibre, capable of enduring long continued Use under full Charges," Memoirs of the American Academy, 1856.

"A careful examination by Russian engineers of cross sections of the Rodman gun shows that it frequently happened that the least contracted layer was very near the walls of the bore; sometimes, indeed, the latter are not only *not* contracted, but are actually under a slight strain of extension. M. P. Holostov abandoned the natural hooping of cannon extolled by Rodman, and recommended hoops of steel for all such cannon manufactured at Perm, or at the Oboukhoff works." Notes on the Construction of Ordnance, No. 21, Washington, May 14, 1883, p. 8.

According to the Report to the United States Senate by the Joint Committee of February 15, 1869, it appears that 23 of Rodman's cast-iron rifles burst in service; 10 burst spontaneously; 5 of them burst in the lathe, one with the report of a six-pounder; two burst while standing in the pit at the foundry. Of 43 Rodman 15-inch guns cast for the Navy, which was the greatest number in service at any one time, 17 have burst or been disabled.

strength of the materials to which it was applied. Thus, he takes the force which acted upon it at 100,000 pounds to the square inch. Now the instrument was held to the gun by a screw formed in the cast iron body of the gun, one and a half inches in diameter, and one and a half inches deep. This gives an area of the plug of the instrument of 1.75 square inches, which received the full pressure of the fired powder. The pressure upon the end of the instrument, then, was $1.75 \times 100,000 = 175,000$ pounds, or about eighty tons. He must be a very bold engineer who would sleep under a weight of ten tons suspended over him by a bolt tapped into a hole in a cast iron plate one and a half inches in diameter, and one and a half inches deep, and yet it does not seem to have occurred to Captain Rodman, that eighty tons' pressure must have driven his instrument from its place." *

In 1862 Mr. Treadwell invented and completed the construction of a device or apparatus for firing cannon, and at the same time closing the vent and keeping it closed during the discharge of the gun. It is described as follows : —

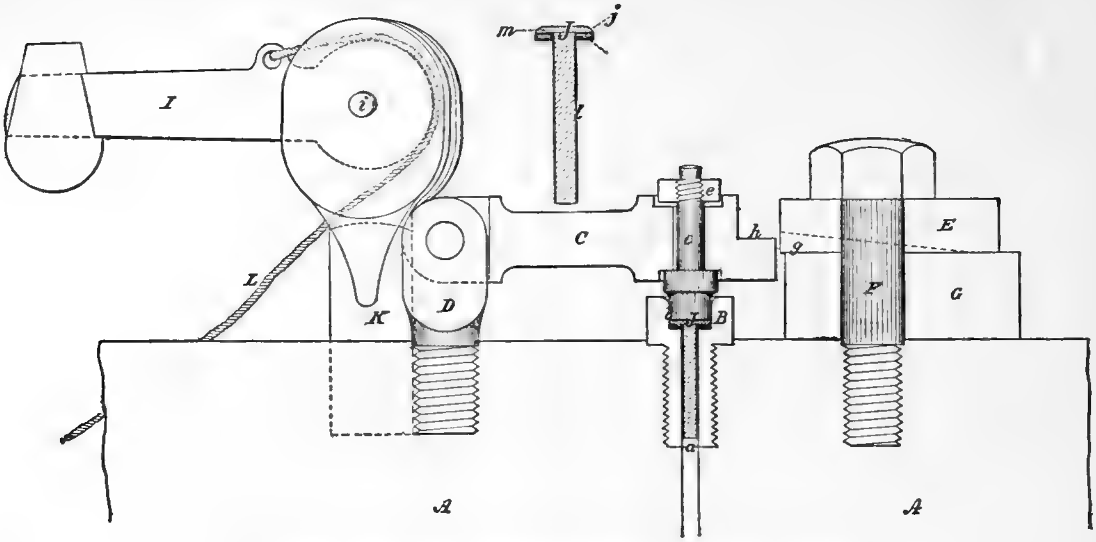
"This invention relates to the construction of apparatus for discharging guns or ordnance, and is designed to obviate certain difficulties attending the mode of construction now usually employed, which will be briefly noticed in order to afford a better understanding of the conditions to which the improvements more particularly apply.

"In the guns now used, the fire for igniting the charge is communicated to it through an orifice in the walls of the chamber in which the charge is placed, called the 'vent,' or 'touch-hole,' by means of priming which is ignited by fulminating powder of some kind, or by the direct application of some incandescent body to the priming powder. When the explosion of the charge takes place, the vent, being open, permits a portion of the gas produced from the charge to escape through it during the whole time that the projectile is within the gun. This gives rise to certain difficulties which it is the object of this invention to remove. The gases within the gun thus escaping through the vent at the moment of explosion under an enormous pressure, and perhaps also by their chemical agency, produce corrosion of the surface of the metal within the vent, and rapidly wear and enlarge it so as to require it to be replaced after a few hundred discharges by an operation well known as 'bouching.' The vent when new has to be sufficiently large to insure its being easily kept free from clogging, and from its further rapid enlargement ; the proportion of the charge that escapes through it becomes very considerable in guns firing the ordinary round shot with windage, and the evil is greatly aggravated both as to the amount of waste of charge and wear of vent by the greater pressure of the gases in the gun when an elongated projectile is fired without windage, as is the case with modern rifled guns. The escape of this amount of gas from the vent, in addition to the wear and waste produced, is also very prejudicial when the gun is fired with the breech in some confined space, such as the casemate of a fort, or the between-decks of a ship of war, where the fire is dangerous, and the smoke becomes a serious inconvenience to the gunners."

---

* "On the Construction of Improved Ordnance as proposed in a Letter to the Secretaries of War and of the Navy, and the Chiefs of the Bureaus of Engineers and of Ordnance of the United States," by Daniel Treadwell. Cambridge, 1862.

Mr. Treadwell's conclusions are fully confirmed by Captain C. S. Smith's experiments at Sandy Hook, in 1881, by dropping from a height Captain Rodman's instrument. "Gun-making in the United States, by Captain Rogers Birnie, Jr., Ordnance Department, U. S. Army." Monograph VIII., Military Service Institution, New York, 1888, p. 54. See also Report of the Chief of Ordnance for 1882 (twenty years after Mr. Treadwell's publication), p. 124.



An Elevation in Section of the Device for Firing Cannon.

A A represents a portion of the breech of a gun. B is a steel plug screwed into the gun, through which the vent *a* is bored, and extending into the calibre. The upper or outer part of the vent is enlarged to form a recess or chamber, *b*, into which the priming cap is placed. C is a strong lever called a "sett stock," which is jointed at one end to the stud D, screwed into the gun, which permits the other end to be turned back from the vent out of the way; in the end over the vent is a steel set or punch, *c*, the lower end of which fits close in the socket *b*; the other end passes up through the sett stock, and has upon it a screwed collar, *e*. The sett is made with a shoulder that bears against the under side of the sett stock, and fits it loosely. This sett serves the double purpose of a vent stopper and a striker for igniting the primer. This end of the sett stock is held down by the button E, which is a disk of steel having a segment cut off from one side, and rotating upon the steel bolt F by means of a handle (not shown in the figure) screwed into it. The button rests upon a lock-piece, G, secured to the gun. The underside of G is made for a part of its circumference in the form of a helical wedge, or inclined like a portion of a square screw thread. When the button is turned by the handle, the inclined surface *g* passes over the lip *h*, which is also bevelled to correspond to it, and forces the sett *c* down upon the cap J, and holds it firmly against the force of the discharge. I is a hammer moved by a lanyard, as is common. J is the primer, also shown separately. It is made of two disks of copper: the upper one, *j*, is made thin, and has its edge turned down outside of the lower one, *k*, fitting closely to it. Between these disks the fulminate, *m*, is placed. In the centre of the disk *k* is a small hole, into which the quill or paper case *l* is placed for holding the priming powder. The explosion of the fulminate expands the flange of the disk *j* against the sides of the recess *b*, and effectually closes the joint to the escape of the gas.

In the patent, dated November 25, 1862, the claim is as follows: "What I claim is the employment in combination with the vent of a gun of a recess, or receptacle, upon the exterior thereof, for containing a primer and a vent-stopper for closing the same, and a primer with an expanding case, which serves as a packing to close the joint and prevent the escape of the gas."

A working model of the priming device is at the Observatory of Harvard College. It has been frequently tested by enclosing in the instrument enough powder to half fill its cavity, and fastening the button down firmly and firing. No report or noise is at first heard, and neither fire nor smoke is seen. But in a few seconds there is a slight blowing from the gas escaping or leaking by the side of the primer, and a smell of sulphuretted hydrogen. Sometimes most of the gas is held in the vent for hours, so to speak, bottled up.

A working model was placed in the hands of M. Souchard, Consul for France at the city of Boston, to be forwarded as a present to the French Government. With the model went also carefully written directions for its use. In a letter to M. Souchard, Mr. Treadwell writes: —

> "On the supposition that the Emperor will deign to accept of my present, permit me to suggest, in order that his examination of it may be made with the least labor to himself, that on reaching its destination it be placed in the hands of some *skilful working engineer*, who shall master the mode of operating and experimenting with it to demonstrate the ease and certainty of its action, and that he be directed to exhibit it to His Majesty.
>
> "To facilitate the right understanding and working of everything connected with it by the person to whom it shall be intrusted, I have drawn up for his use a full description of the machine, and the mode of charging and firing it, with a notice of all it is necessary to observe to avoid any failure or accident. This description is enclosed with the instrument. I lament that my imperfect knowledge of the French has obliged me, in writing it, to use my own language.
>
> "I have likewise taken the liberty to enclose in the case, in the hope that His Majesty will accept it, a small volume comprising several memoirs relating to cannon that have been published by me, and which give an account of some part of my long continued labors."

The present was accompanied by the following dedication: "Appellatio ad Cæsarem. . . . Presented to His Imperial Majesty, Napoleon III., Emperor of the French, with the most sincere and most profound respect and admiration. The Author. Cambridge, December, 1862."

The device was carefully examined by the Emperor personally, and a special commission appointed by the Minister of War to examine and report upon its merits. A special letter of thanks was also directed to be sent to Professor Treadwell through the Consul for France at Boston.

Soon after its invention Mr. Treadwell gave a full description of it to several officers of the United States Navy, and also sent a description to the proper Department at Washington, but from the latter received no acknowledgment.

In concluding his Autobiography, Mr. Treadwell says: "Besides the failure of securing for my first gun its adoption by the Government, I have wasted some years of my life upon two other projects from which no good practical results have followed. One was a machine for making wrought iron nails and the other a machine for setting types. In both I succeeded in producing machines to operate as perfectly as I promised myself in the outset. But neither, on actual trial, gave the promise of profit that would alone warrant attempting the establishment of them as practical instruments in the arts."

The following letter to Professor Treadwell from Lieut.-Colonel W. de Raastoff, Chargé d'Affaires de S. M. le Roi de Danemark, and his reply, are here given.

Lieut.-Colonel Raastoff to Daniel Treadwell.

Danish Legation, Washington, September 19, 1862.

Sir, — Having read with considerable interest two pamphlets published by you, bearing the titles, "On the Practicability of Constructing Cannon of great Calibre, 1856," and "On the Construction of Improved Ordnance, 1862," I take the liberty most respectfully to solicit from you one or two copies of each of those publications, in case you should be able to spare as many, with a view of sending them to my government. I may be allowed to mention that I have been an officer of ordnance for a number of years, and that I have ever since taken a lively interest in the discussion of the question which you treat with so much authority, and, in my humble opinion, in a manner both lucid and novel.

The two pamphlets were lent to me for perusal by Mr. Norman Wiard, who has derived much information from them, and who encouraged me to solicit copies from you.

Hoping that you will not think me indiscreet in addressing myself directly to you without having the advantage of your personal acquaintance, I have the honor to be, with high and sincere regards, your very obedient servant,

W. Raastoff.

Daniel Treadwell to Lieut.-Colonel Raastoff.

Cambridge, December, 1862.

Sir, — In compliance with the request contained in your letter of the 19th instant, I forward to you with great pleasure duplicate copies of my several papers and memoirs on the improvement of ordnance.

I pray you to accept the assurance of my sincere gratification at the approbation you have been pleased to express of my investigations, an approbation especially valued as coming from one practically acquainted with the subject by having been an "officer of ordnance for a number of years." I have the honor to be, with much respect, your obedient servant,

Daniel Treadwell.

At the monthly meeting of the Academy in May, 1863, Mr. Treadwell read a paper on the effect of cannon shot upon iron-clad ships and armor plates generally, being a sequel to the memoir "On the Practicability of constructing Cannon of Great Calibre," published in the sixth volume of the Memoirs.

In this paper it is proposed to substitute for a globular shot one of a cylindrical or prismoidal form, with a steel face with sharp corners, the length of the cylinder being less than its diameter, its rotation from the rifling being about the shorter axis of the body. "Should any practical difficulty arise to disturb the directness of its flight from the want of length in the cylinder, it may be lengthened by giving greater length to the sides for the rifle grooves or projections, and a most effectual disposition to the metal for driving the corners through the plate, while the weight is collected more in the head, as it is in its prototype, the shuttlecock. Or it may be made with cavities, which may be left full of the core sand, or filled with powder for exploding within the ship." It was proposed to make these shot 28 inches in diameter. The gun from which this missile is to be thrown is that described in the sixth volume of the Memoirs, "in which the strength should follow the ratio of the thickness in contradistinction to the common cast iron gun, to which no thickness can ever be given by which it can be made to sustain a charge beyond a very narrow amount."

"Under the conclusions that I have exhibited, I can see no limit to the increase in the size of cannon; but as a gun of this kind of 28 inches calibre must be made to weigh about 90,000 pounds, it will of course be out of the question to carry such on shipboard, while they may well be borne by the solid earth. This will give to the fort, and consequently to defensive war, a great advantage over offensive war, a fact that may be greatly in favor of civilization and humanity."

The following letters indicate the value placed upon Professor Treadwell's labors by the Instructor of Ordnance at the West Point Military Academy.

TO PROFESSOR DANIEL TREADWELL.

WEST POINT, N. Y., January 21, 1865.

Dear Sir, — Being the Instructor of Ordnance and Gunnery at this place, I am, of course much interested in the progress of the art of making guns of great endurance. I have read your pamphlet on the "Practicability of constructing Guns of Great Calibre," and your printed letter of December 23, 1861, addressed to the Secretaries of War and Navy, with interest, and am satisfied that in this matter of built-up guns, made on scientific principles and carried out practically, you are without doubt entitled to the credit of being the first in this country to succeed in solving the problem, and so far as I know were in advance of any one in England. In order that I may fully understand all that you have accomplished, and be able to give my pupils a clear idea of what you have done in this branch of manufacture, I should like to obtain your account of the manufacture of the first guns made on your plans, as published by you in 1845. This pamphlet I have never seen, and know of no other way to obtain it than to address you on the subject.

In a matter of military history of this kind, I desire to be able to give all the facts, and give credit where it is due. Any information you can give me as to how I can obtain this paper, I shall be much obliged for.

I remain, with much respect, your obedient servant,
GEO. F. BALCH, *Capt. Ordnance Corps U. S. A.*

TO PROFESSOR DANIEL TREADWELL.

WEST POINT, N. Y., January 28, 1865.

Dear Sir, — Your favor of the 25th reached me yesterday, but I have delayed a reply until I could at the same time acknowledge the receipt of the package by express, which came to hand to-day.

For your kindness in thus complying with my wishes, please accept my thanks, and in return I shall make it a duty to see that the graduates of this Academy who have been under my tuition clearly understand what is due to your labors in developing new ideas on the subject of heavy ordnance, and how much you have been in advance of our English contemporaries in this matter.

The Ordnance Department is at present wedded to cast iron, and in Rodman's method of casting seems to see a solution of all difficulties; but experience dearly bought is the best teacher, and sooner or later the cast iron must go to the wall.

With many thanks for your invitation, of which I shall be happy to avail myself should I at any time visit Cambridge, I remain, with much respect, your obedient servant,
GEORGE F. BALCH.

The following letters to old friends were written about this time.

TO PHINEAS DOW, ESQ.

CAMBRIDGE, February 5, 1865.

My old Friend, — I received, with great pleasure, a letter from you several months ago, which, having nothing particular to write to you, I have hitherto omitted to answer. It gave me much satisfaction to know, under your own hand, that you were then in good health and still able to attend to the old occupation, and I sincerely trust that this state of comfortable old age has been continued to you. For myself, I have been and am in as good health as has been my usual lot for many years, and as my means are enough to supply all my wants, I have nothing to prevent a fair share of enjoyment in life. As I have no child to come after me, I am at least without particular anxiety for any that I may leave, except indeed my wife, who can have no very long future after I am gone. It has been her good fortune to improve in health as her age has advanced, so that she is stronger now than she was twenty years ago. I give much time to reading, and yet amuse myself with *inventing*. My lawsuit with Mr. Parrott has given me much labor and cost for the last three years. The testimony in this is now all taken, and I shall, in all probability, obtain a trial in the coming March or April. My case seems to me and to my lawyers a very strong one, but we cannot foresee the quirks of the law nor the caprices that may take the courts. The trial will be by Judge Nelson, of New York, who has the reputation of an able man. Should I fail in this suit, I shall at least establish full proof to the world that all the most important improvements in cannon that have been made for the last twenty-five years have been derived from me, and most of them reduced to practice by me.

I have mislaid your address, so that I must send this to you directed merely at Philadelphia. I wish you, immediately on receipt of it, to return an answer, enclosing the direction to your street and number. I wish you to do this, as I have something to send you by mail, and it will be important to you that it should not miscarry. I will enclose it as soon as I receive an answer to this, and your address.

Wishing you continued health and comfort, I remain, very truly, your friend and servant,

DANIEL TREADWELL.

P. S. Let me know how Mr. Ashmead flourishes in these times.

TO DR. WILLIAM SWEETSER.

CAMBRIDGE, April 15, 1865.

My dear old Friend, — You cannot think how much I rejoiced, some three months ago, in the account which I received of you from my friend and neighbor, Mr. Charles Folsom. From the correspondence between Mrs. Treadwell and Mrs. Sweetser, likewise, and from Miss Langdon, I have received constant accounts of your recovered health. This has been a very great source of satisfaction to me, for I can say, with the utmost truth, that there is no person left in the wide world whose welfare I so sincerely desire as yours. I will not say a word about my neglect in not writing to you, as you know my *idiosyncrasy* about mere friendly correspondence and must lay my conduct to that fault. The world has gone on with me during the past winter much in the old way. My health has been uncertain, sometimes quite comfortable, sometimes feeble, but without any particular disease, except the weight of years, which has told upon me very much since I last saw you. I feel myself much alone in the world. I feel the loss of Ware very much, and I yet miss the relief I used to find in the company of old T. I see more of Mr. Folsom than anybody else, as he lives near me, and usually calls in two or three times a week. But my dear old fellow, if I only had you within speaking distance, to go over the old memories with, and discuss the questions and *humbugs* of the day with, it would be worth all else that is left to me. My mind remains very active, and although I avoid putting it to very laborious and long-continued work, yet I find myself capable of pursuing my old subjects of investigation with satisfaction, and *as I think* with vigor.

Accept Mrs. Treadwell's best remembrance and love to Mrs. Sweetser, and from me to Mrs. Sweetser all kind regards.

Ever truly yours,

DANIEL TREADWELL.

At the annual meeting of the Academy, in May, 1865, when Professor Treadwell declined a re-election to the Vice-Presidency, to which he had been annually chosen since 1852, Professor Jeffries Wyman moved the following vote, which was unanimously adopted: —

" *Voted*, That the thanks of the Academy are hereby respectfully tendered to Professor Daniel Treadwell, for the constancy with which he has devoted himself to their interests, for his valued contributions to their Memoirs, and for his uniform urbanity and fidelity in the performance of the duties of the office of Vice-President, which he has honorably filled for many years."

In 1865 Professor Treadwell received from the Academy the Rumford medals. During the thirty years that the Academy had been charged with the award of this premium, it had been given to but two persons; never to a member of the Academy. It was now given to Professor Treadwell for his "Improvements in the Management of Heat." The award was most grateful to him; it assured him that, however much his labors had been slighted by his own Government, they were fully appreciated by a competent scientific tribunal, and his claim to originality recognized. It is to be hoped it did something towards relieving the periods of depression of spirits into which he not unfrequently fell, for it must surely be a satisfaction to find one's labors appreciated by the few who are competent to pronounce on their value.

The following is the vote recommended by the Rumford Committee, and unanimously adopted by the Academy, at its annual meeting, May 23, 1865.

"Whereas Professor Daniel Treadwell, of Cambridge, Massachusetts, between the years 1840 and 1845 did devise, execute, and publish certain improvements in the management of heat by which guns of great strength and endurance were constructed, especially by the coiling of iron in the direction of its greatest tenacity, and welding the coils by means of moulds and mandrels and by hydraulic pressure into a hollow cylinder, whereby a system of construction, before used in small arms only, was rendered applicable to guns of any calibre, and which is now generally adopted in the manufacture of large cannon, — therefore the Rumford Committee recommend to the American Academy of Arts and Sciences that the following vote be passed: —

"*Voted*, That the Rumford Premium be awarded to Professor Daniel Treadwell for improvements in the management of heat, embodied in his investigations and inventions relating to the construction of cannon of large calibre, and of great strength and endurance." *

The award was carried into effect at the Academy's rooms on the 15th of November, 1865.

The President of the Academy, after a concise statement of the investigations, inventions, and labors of Mr. Treadwell, and the consequences to which they have led, said: —

"And now, Mr. Treadwell, in delivering into your hands this beautiful gold medal and its silver duplicate, I have much pleasure in conveying with them the congratulations and best wishes of your associates here assembled; also the expression of their hope that you may yet longer lead the race of improvement; and, especially, that you may long enjoy the scientific honors which you have worthily won; and with them, if it may be so, have the full recognition of the rights and possession of the advantages which pertain to your inventions."

---

* Professor Treadwell adds in his copy of the vote: "Which were carried into practical operation by him A. D. 1842. — D. T."

Mr. Treadwell expressed his acknowledgments as follows.

"Mr. President, and Gentlemen of the Academy, —

"I receive with great satisfaction the Rumford medals, which, in accordance with a vote passed at the annual meeting, you have now presented to me. I prize this premium the more as coming from this body, with which I have been intimately associated for more than forty years as an active member, and for a very large part of the time as an office-bearer. I may be permitted to say, however, that, although I am sensible that I am indebted for this award in a large degree to your kind partiality for an old associate, which turned your attention to his labors, yet it was made not only without any application on my part, but your motion towards it was wholly unknown, and not even thought of by me, until the vote of the Rumford Committee was communicated to me.

"The award was, as stated in your vote, (which uses the language of the Count Rumford,) for 'improvements in the management of heat.' But as this management of heat was incidental to and intimately connected with improvements in the construction of cannon, to which I had given years of labor, you have extended your examination into the character of these improvements generally. For the very thorough research which it is evident you have made into the whole subject, I feel under great obligations to you; and the very favorable conclusions which you have reached, and which have been so fully and kindly expressed by you, sir, as to the originality and value of my researches and labors, form an additional source of satisfaction to me. This, taken alone, would constitute one of the most welcome recognitions and rewards that could be given to me. Permit me, in conclusion, to express my special obligations to the members of the Rumford Committee for directing their attention to my labors, and for the very favorable view which they have taken of their merits." *

Of the many congratulations on the reception of the Rumford medals, the following is from his friend, Admiral Charles Henry Davis.

To Professor Daniel Treadwell.

Washington, November 23, 1865.

My dear Friend, — I have for some time been meaning to write to you a single line to tell you with how much satisfaction and improvement I have read, this autumn, very carefully, the several papers — contained in the volume you gave me last summer — on your method of constructing cannon. I wished also to learn from you the result of your suit against the Parrott gun, and to ask you to send me the proceedings in the case, if they have been published or printed.

No one of your friends is more fully alive than I am to the injustice and the painful disappointment you have suffered; and I know it is but a poor consolation to dwell upon the certain recognition of your claims hereafter.

But it is most gratifying to me to see that the testimony of the highest authority has sustained your originality and done honor to your inventive genius.

The presentation of the Rumford medal is the best and the sufficient vindication of your rights, and a proper rebuke to those, both at home and abroad, who have stolen your invention.

During the war I was chairman of a commission (of which General Barnard of the Engineers, Professors Bache and Henry, and Mr. Saxton were members) for examining inventions offered

---

* Proceedings of the Academy, Vol. VII. p. 144.

to the Departments, and I was struck in some instances with the extravagant and unscrupulous eagerness of common persons who thought they had discovered a way of getting rich.

I hope the decision of the court in your prosecutions of the Parrotts will award you — what you value more than money — the honor and merit of being the first to conceive of, and to employ, coiled spiral rings in the construction of wrought iron guns.

Pray remember me most cordially to Mrs. Treadwell, and believe me your constant and faithful friend.

C. H. Davis.

Professor Winlock of the Harvard College Observatory, at a meeting of the American Academy, September, 1866, read a paper by Professor Treadwell "On the Comparative Strength of Cannon of Modern Construction."

The standard gun is assumed to be the old 32-pounder, with a charge of eight pounds of powder and one shot, with an initial velocity of 1,600 feet a second; the standard unit of force is taken as the height to which the shot would rise *in vacuo*, or 40,000 feet; this multiplied by the weight of the shot, 32 pounds, gives 1,280,000 pounds raised one foot in one second as the measure of force.

To determine the strength of the gun, as well as the force of the shot: "Having already seen that our standard 32-pound shot has a force of 1,280,000 pounds raised one foot, if we divide this product representing the strength of the whole gun by the weight of the metal of which the gun is made up in pounds, we shall obtain the strength or work which may be done by one pound of the metal of which the gun is constituted. We shall find the result of this computation (the weight of our standard 32-pounder being 7,500 pounds) to be ($\frac{1280000}{7500} = 171$) 171 pounds in shot raised one foot by every pound of metal which forms the body of our standard gun."

This computation, applied to the Dahlgren, Rodman, and Armstrong guns, gives the following results. The number of pounds of shot raised one foot by each pound weight of the gun is, for the Dahlgren, 144.7 pounds; the Rodman, 125; the Armstrong, 372.8.*

To Dr. William Sweetser.

Cambridge, November 4, 1868.

My dear old Friend, — I received your most kind letter early in September, but my infirm state and some special annoyances have prevented me from answering it until this late day. A letter from you is always most welcome to me. It is especially so now, when oppressed with pain and many infirmities. I am heartily glad to know that your health has continued sound notwithstanding your seventy years, and that you make light of the *Davidian* period; that you can walk at pleasure, and, as I trust, have the advantage of a good appetite for food, and the enjoyment and vigor that flow from indulging it. I congratulate you also on the philosophical quiet

---

* For correction of error as to Armstrong gun, — 261 instead of 372.8, — see Proceedings of the American Academy, September 11, 1866, Vol. VII. p. 412.

of your mind, by which you wait the doom of *inexorable nature.* How much I should like to talk with you, as we did formerly, upon this subject, and its collateral, *Pantheism*, and the probability of an actual though *immaterial existence* after this mortal life. But however much I should like to compare present thoughts and conclusions with you by the "living voice," I find myself altogether unable to write about it. Doubt, doubt, and still doubt. But all gravitating to the theory of development from simple attributes, properties, or tendencies, inherent in *matter*, of the origin of which we can form no conception. The legitimate tendency of all this is, as it seems to me, the reception of Darwin's idea of the law of "natural selection under the struggle for life," and thus (the order or laws of nature being established *of necessity*) it becomes possible to conceive of the formation of both the material and of the organic or living world *without design.* Who that shall receive this conception as true, — and it seems to me that the whole tendency of the scientific discovery of the age is towards this theory of development, — who, I say, that shall receive this will not find his mind sooner or later lean to the conclusion *that man, or the human mind, is the highest self-conscious intelligence (or intellectual power) in the universe?* . . .

You ask me to write to you about the present state of my health and of my occupations, or the way in which I pass my time. The last two and a half years which have passed since I saw you have told severely upon my strength. Still I have kept up "the struggle for life," have rode almost every day, and have walked some; and although I have *broken* much in mental as well as in bodily health, I am still capable of some enjoyment. I have certainly been less afflicted with that *cruel pain*, for which I was obliged to resort to the use of opium, than formerly, so that for the last two months I have been able to live entirely without taking it. But having now passed my *seventy-seventh* year, I am fully sensible that the end is very near me, and that all that I can hope is that it may come without the pain that sometimes attends it. It is hardly to be expected that you and I can ever meet again (although I will not give up the hope that we shall). I trust, however, that you will continue to write to me often, even if I should live after I become unable to answer your letters. With this, and my best respects — shall I not say love? — to Mrs. Sweetser, and communicating Mrs. Treadwell's love and best wishes to you both, I take my leave for the present, with the assurance that, living or dying, I shall remain your sincere friend.

D. TREADWELL.

DR. ASA GRAY TO DANIEL TREADWELL.

AMERICAN ACADEMY OF ARTS AND SCIENCES,
Boston, Massachusetts, May 30, 1871.

My dear Sir, — At the annual meeting of the Academy held this day, I had the pleasure to read the letter which you did me honor to address to me as President, enclosing your check for *two hundred dollars*, to be applied to the making of a full and complete index of the Works of Count Rumford, which the Academy is now collecting and editing. And I have indorsed over the check to the Treasurer, who is instructed to hold the proceeds as a separate fund, safely investing it until the time for using it arrives, when the Academy is pledged to expend it in the production of as perfect an index as can be made.

And the Academy, on motion of Professor Agassiz, seconded by the Chairman of the Rumford Committee, unanimously voted, "That the cordial thanks of the Academy be presented to its associate, Professor Daniel Treadwell, for this very thoughtful and generous gift."

In the ordinary course, this vote would have been communicated to you, in an attested copy, by the Recording Secretary; but I offered to attend myself to this duty, in order that the grateful acknowledgments of your associates in the Academy might the earlier be presented to you, and that I might personally have the pleasure of expressing to you my own deep sense of the many and important services which you have rendered to the Academy, and to science and the arts, of which the younger members of the Academy, now taking our places, can have little conception, commencing as they did long before I, a Fellow of thirty years standing, became your associate and friend, while to-day the Academy has had pleasant and substantial evidence that, although unable to attend its meetings, your interest in its welfare and usefulness is unabated.

Heartily wishing that it may please the supremely good Providence that orders the lives of men to preserve yours still to us, and render your later years happy ones, believe me, my dear Mr. Treadwell, very sincerely and faithfully yours,

Asa Gray, *President.*

When Mr. Treadwell entered upon his duties as Rumford Professor he built for himself on Quincy Street a house, which stands opposite Memorial Hall. Here he lived till 1848, when it was purchased by President Sparks. His second house in Cambridge he built on Concord Avenue, opposite the end of Craigie Street. It is a square house with a hipped roof and sheathed walls, and standing but a little raised above the natural surface of the ground. Here he passed the remainder of his days. It is surrounded by an ample garden, and has a stable; near this were arranged, side by side, the three cannon of his manufacture, given to him by the Steel Cannon Company when it ceased operations. In the vicinity he found much that he desired; near by are the College Observatory, of which his friend Professor Joseph Winlock was then the Director, and the Botanic Garden, where was another of his warmest friends, Dr. Asa Gray. The country roads along which he so often rode for health and pleasure are easily reached. The College Library is at a short distance, and his College friends within an easy walk. Cambridge in its social aspects offered much that contributed to his comfort. There are in this University town, not only men of science and literature connected with the College, but also others who find here a society congenial with their tastes and habits. His intercourse with these gave him much pleasure.

Mrs. Treadwell says of her husband: "The years he was about the gun were happy ones with him. In the winter, after a very simple breakfast, he left home for the Mill Dam about eight o'clock, with all the glee of a schoolboy, with his lunch and a bottle of tea, and did not return till quite dark. In the evening he liked a game of whist, and was always glad when a friend came in for a rubber. I do not think the non-adoption of the gun by the Government, after the first disappointment was over, depressed him so very much; it certainly did not prevent his enjoyment of things abroad. But he always had a feeling that the gun would ultimately succeed, in one form or another, and through his invention."

That he had such hope the following dedication on the fly-leaf of his paper on the Hooped Cannon fully indicates: "'Transported me beyond this ignorant present.' . . .

Respectfully dedicated to the engineers of the twentieth century by the author. Cambridge, July, 1864." Below this is the following: "This work, written in the middle of the nineteenth century by an engineer who was born in the eighteenth, is paternally and lovingly dedicated to the children of his profession who may live in the twentieth."

Still he writes to Dr. Sweetser: "Time passes quietly, but I cannot say that it goes happily. The want of success in my gun leaves a mark which it will be hard to rub out."

The civil war was to him a sore trial. To Dr. Sweetser he writes, "The Union split in two and the Constitution gone! Alas for the great Republic!" He saw in the future only border warfare and ruin to a once prosperous nation. Fortunately he lived to see the war ended, and his country gradually recovering from its dreadful calamity.

The tendency of his mind was essentially experimental. "He had the ingenuity of the mechanical inventor, and the philosopher's passion for truth." Difficult mechanical problems seemed to have for him a strange fascination, from which he was only to be delivered after he had reached a satisfactory solution. He was an excellent experimenter, and a skilful handicraftsman. It must have been rare that a conclusion at which he had arrived by experiment was successfully attacked. He seems to have been of John Hunter's mind when Edward Jenner asked his opinion of a theoretical solution: "I think your solution is just. But why think? Why not try the experiment? Repeat all the experiments, and it will give you the solution." He might have said with Leonardo da Vinci, "Instrumental or mechanical science is the most noble, and of all the most useful, seeing by means of it all animate bodies that have motion perform all their operations."

Mr. Treadwell did not place a very high value on scientific knowledge alone, as leading to great mechanical inventions, but was well aware that those who have made such inventions have been under the influence of the knowledge of the age, and received aid from their acquaintance with facts which had been disclosed by scientific investigations. The peculiar combination of qualities intellectual and moral to give effect to scientific knowledge so far as this has been required to produce the great practical results witnessed within the last hundred years, he thus enumerates: "It is a combination of clear and active perceptive faculties, high imaginative power, a great faculty of comparison, a determined will, and a never tiring perseverance, together with knowledge at the disposal of the imagination which can create and combine shapes never before seen, and trace the course of motion through series of bodies never before combined." These qualities he possessed in a marked degree.

As to his religious belief, "his was a mind in which science seemed to have taken the place of theology, in which only inductive, or, as it has been called, 'concrete evidence,' has real weight." In a letter to Dr. John Ware he writes: "Your kind attention to my *faith* deserves my gratitude. I consider the Christian's belief as of more value than anything else he can possess in this world; but from the peculiar construction of my mind, I sadly fear it is not a treasure for me. Now if I could gain this by asking, I should ask loud and often. Still, I hope you do not put me down for an outright Deist, but merely a sceptic in religion. I would believe, because I admire the character of Jesus Christ, and, more than all, because I think the immortality of the soul cannot be proved by natural religion, and there is something inexpressibly cold and gloomy in the bare idea of annihilation; I could almost as comfortably think of going to Purgatory as being annihilated."

As the tendency of his mind was essentially experimental, it is not surprising that in theological matters he had little respect for decisions or decrees of persons or bodies claiming authority without the support of reasons satisfactory to himself. Although he could not accept the prevailing theology of the time, he seldom spoke of his doubts unless called out by others. He was unwilling, he said, to disturb the faith of those who found in it so much hope and comfort.

Dr. William Sweetser writes of his friend:—"I became acquainted with him, to the best of my remembrance, when a medical student, about the year 1816. I knew him as a profound thinker, close reasoner, a kind friend, noble, true, and generous in all his impulses. He was critical by nature, but he always aimed at what he believed to be truth and justice. For no advantage would he deviate one jot from what he viewed the right and honorable path. Like others, he was ambitious, but his ambition was of the worthiest character. The closer our intimacy with him, the higher did we esteem him. Though he might sometimes appear cold and reserved to a stranger, yet to his friends he was ever free and warm-hearted. At that early period, we, his friends, held him in high esteem and respect for his great scientific attainments and his intellectual superiority, which we did not hesitate to acknowledge. I became greatly attached to him at that time, and that attachment has never met any interruption. I fully appreciated, I believe, his high intellectual and moral character. He had warm affections, and noble, generous impulses. But no one could surpass him for the strict justice of his character. Truth seemed a part of his nature. It may well be said of him, that he 'would not flatter Neptune for his trident, or Jove for his power to thunder.' He lived to more than the common age allotted to man, and died honored and respected, without a blot on the purity of his character."

From early youth he was never physically strong. He was himself impressed with the belief that he should, sooner or later, succumb to pulmonary disease. His health in middle life improved, but was never firm. During his most active periods he had attacks which often stopped him in the midst of his labors, and compelled him to remain at rest for weeks together. The summer heats exhausted him; for relief he took frequent journeys in the country, especially through the valley of the Connecticut, and in the spring, to escape the chilling east winds of New England, he twice journeyed to the South. In later years he suffered from severe bodily pains; they weakened and depressed him; still he was interested in what was going on, and kept himself informed of the progress in science and the discoveries and improvements in the arts. His painful attacks still pursuing him, he withdrew from his club, and went but little abroad except for exercise in his carriage. On the night of the 26th of February, 1872, his sufferings were more severe than ever; his remedies gave partial relief, so that he fell asleep. From this sleep he never awoke to full consciousness, and died early in the morning of February 27th, in his eighty-first year.

Three days later, after simple and solemn religious rites in the presence of his relatives and many friends, he was borne to Mount Auburn.

The will of Daniel Treadwell is dated November 7, 1863, and contains the following public bequests. The inventory of the property amounted to $55,674.

"I give, devise, and bequeath to my native Town of Ipswich, in the County of Essex and Commonwealth of Massachusetts, all my real estate situated in the said town, to have and to hold the same forever, the income whereof, together with the sum of four thousand dollars, which I hereby give and bequeath to the said town for the same purpose, shall be appropriated by the said town for the purpose of founding a Library, to contain a collection of the standard works of the best authors, ancient and modern, but to the exclusion of the cheap literature and party newspapers of the day, for the use of the inhabitants of Ipswich and the neighboring towns; and it is my wish that the building for the said library shall be erected upon the land purchased by me near 'The Stone Bridge' a few years since, that it shall be made fire-proof, and used exclusively for the purposes of a library."

"It is also my will that my wife shall have and use all my pictures, but that at her decease five of the copies in oil of the pictures of famous Italian Painters shall be given to the Town of Ipswich, to be placed in the Library above provided for. And I further devise that all my papers and manuscripts, not necessary for the settlement of my estate, shall be deposited in the said Library in the Town of Ipswich."

All the remainder of the library, after his wife shall select such books as she may desire, "I give and bequeath to the Town of Ipswich, for the Library above provided for."

All the residue of the estate is placed in the hands of the executors in trust for the benefit of his wife, and at her decease to be divided equally among the following institutions: The President and Fellows of Harvard College, the American Academy of Arts and Sciences, the Boston Athenæum, the Trustees of the Public Library of the City of Boston, and the Town of Ipswich for the Library.

"In order more surely to carry out the intentions of my legacies above made to the Town of Ipswich, I would express my wish and desire that the Trustees of the Public Library of the City of Boston for the time being should from time to time visit the Library at Ipswich to inspect the same and the accounts of the estate, both real and personal, bequeathed by me for its establishment and benefit, and to see, if occasion requires, that the proper steps be taken to prevent or remedy any misuse of the trust."

List of Professor Treadwell's Papers.

1822. Improvements in Machinery. North American Review, Vol. XIV. p. 14.
1825. An Account of the Passage of Water through an Aqueduct being totally obstructed by a Collection of Air. Boston Journal of Philosophy and Arts, Vol. II.
1825. Report on the Supply of Boston with Pure Water.
1827. On a Mode of conducting the Transportation on Railways, and Arranging the Passing Places, to avoid the Necessity of a Double Set of Tracks. "Franklin Journal," Vol. IV. p. 278. Paper dated August 22, 1827.
1828. Report to S. C. Phillips, Benjamin Hawkes, and Perley Putnam, Committee of the Directors of the Salem Milldam Corporation, April 29, 1828.
1829. Reports to the Directors of the Massachusetts Railroad Association on a Single Track.
1833. Description of a Machine called a "Gypsey," for Spinning Hemp and Flax. Memoirs of the American Academy, 1833.
1835. Report on the Weights and Measures of the State of Massachusetts.
1837. Report as Chairman of the Commission on the Supply of Boston with Pure Water.
1838. Report as Chairman of same Commission on the same Subject.
1842. Review: "Practical Treatise on Ventilation, by Dr. Morrill Wyman." North American Review, Vol. LXIII.
1845. A Short Account of an Improved Cannon.
1855. Relations of Science to the Useful Arts. Delivered to the American Academy, November, 1852.
1856. On the Practicability of the Construction of Cannon of great Calibre, capable of enduring long continued Use under full Charges.
1860. On the Construction of Rifled Cannon. A Letter to Hon. John B. Floyd, Secretary of War.
1861. On the Construction of Improved Ordnance, as proposed in a Letter to the Secretaries of the War and of the Navy, and the Chiefs of the Bureaus of Engineers and of Ordnance of the United States.
1861. On the Measure of the Forces of Bodies moving with different Velocities.
1863. On the Effect of Cannon Shot upon Iron-clad Ships and Armor Plates generally. Proceedings of American Academy, May, 1863.
1864. On the Construction of Hooped Cannon; being a Sequel to the Memoir on the Practicability of the Construction of Cannon of great Calibre, etc. Memoirs of the Academy, Vol. VI., 1864.
1866. On the Comparative Strength of Cannon of Modern Construction. Proceedings of the Academy, Vol. VII., 1866.
1868. Answer to Charges contained in an Article in the "Scientific American," October, 1867.

A notice of Professor Treadwell's Papers, by the compiler of this Memoir, was printed in the Atlantic Monthly, October, 1873, Vol. XXXII. p. 470.

List of Inventions.

Machine for making Wood Screws.
Wrought-Nail Machine.
Foot Lever Printing Press.
Power Printing Press.
Injecting Timber with Preserving Fluids.
Circular Hatchel, or "Lapper."
Belted Roving Machine.
"Gypsey."—Machine for Spinning Hemp or Flax.
Apparatus for Tarring Rope-yarns.
Iron Tail for Laying Rope.
Machinery for making Cannon and forming Hoops for Cannon.
Recoil Apparatus.
Device for Firing Cannon.
Tubular Condenser for Steam Engines.
Hot-Air Furnace Regulator.
Improved Backsight of variable Size for Rifles.

SPINNING MACHINE.

Fig. 2

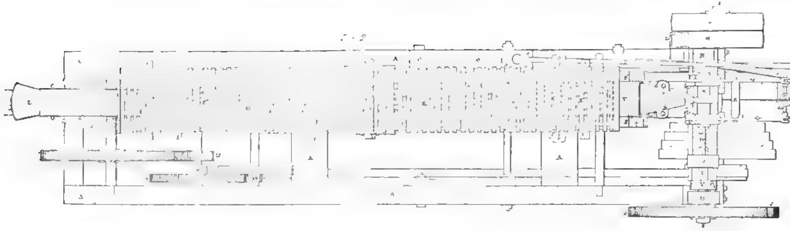


Fig. 13

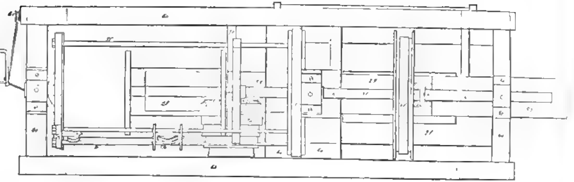
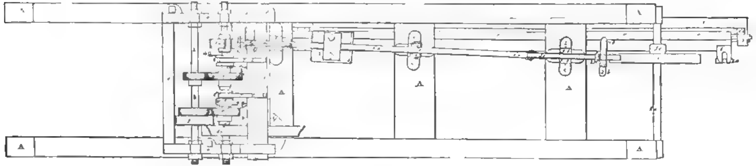


Fig. 1



APPENDIX.

I. — See page 374.

THE SPINNING MACHINE. — THE GYPSEY.

The machine may be considered as divided into two parts; Figs. 1, 2, 3, 4, 5, representing the part by which a small filament is drawn from a column or roving called the *Drawing-frame;* and Figs. 14, 15, 16, the part by which the filament is twisted and wound up, called the *Bobbin-frame.* The same letters and figures indicate the same parts on all the plates.

Fig. 1.

SPINNING MACHINE.

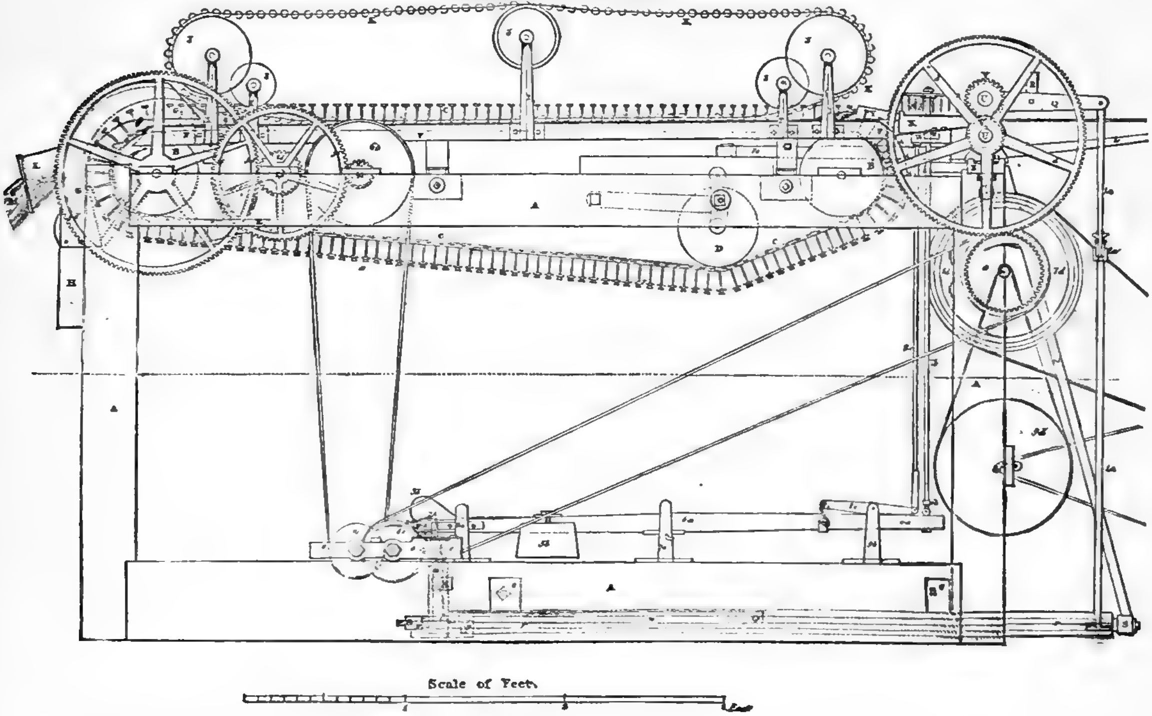


Fig. 1 is the Drawing-frame. It has a hatchel belt, C, with points and clearers upon which the roving lies, and a bobbin-belt, K K′, like the belted roving machine, as will be seen by simple inspection, page 372. It revolves in the same direction as in the roving machine, and has a binder pulley, D, to keep it to a proper tension. The ends of the hatchel plates bearing the points of the hatchel rest or slide on the tops of the rail F F; the belt is kept in place by a plate, E, at the left end of the frame, A. G G are plates of iron attached to the frame, called forcing plates. A tin tunnel, L, is fixed between these plates, G G, for the purpose of directing the roving or sliver of hemp into the hatchel belt; this tunnel runs in the direction of the dotted line between the forcing plates until it nearly meets the bobbin-belt.

The apparatus by which the hemp is carried in the drawing-frame and drawn to form a filament consists principally of two steel rollers, S S, Fig. 4. The lower roller runs in gudgeons in the pillars P P, O O; the upper roller runs in gudgeons in two levers, Q Q, hung by pins forming fulcrums or axes in the pillar P P, Fig. 2. These levers are connected together by the curved iron bar, R, Figs. 2 and 4, so that one cannot rise or fall unless the other rises or falls with it. The *drawing-rollers* S S are coupled by the plates T T to the shafts U U, running in the pillars O O, and connected by the gear-wheel V V. X, Fig. 1, is the gatherer; this is made of plates of iron in nearly the form of an unequal four-sided pyramid, with its open base towards the hatchel-points and its truncated apex opening between the drawing-rollers, being so shaped as to conform to those portions of the rollers which are situated against it. The top of the gatherer, Y, passes off towards the bobbin-belt to receive the roving of hemp and direct it, to the rollers. The top of the gatherer has several slits cut through it, so that the teeth of the comb, 8 *b*, can pass through it. There is, moreover, in the gatherer a false bottom, hung by a joint at the end nearest the drawing-rollers and capable of being swung upwards like a trap-door. This false bottom has slits across it, corresponding with those through the top. In Fig. 4, *a* is a fast pulley on the shaft *b*, to which the power to drive the machine is applied, by means of a belt; *a'* is a loose pulley on the same shaft, *b*, on which the driving-belt runs when the machine is at rest. On the end of the shaft *b* is the pinion *c*, which drives the wheel *dd*, fixed on the shaft U, which is coupled to the lower drawing-roller, S.

Fig. 5.

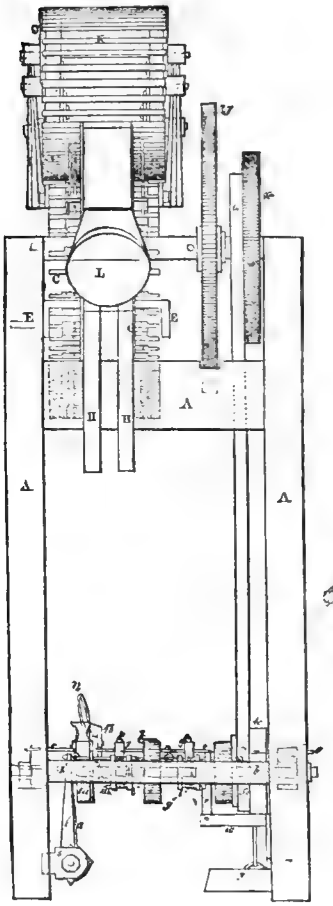


Fig. 4.

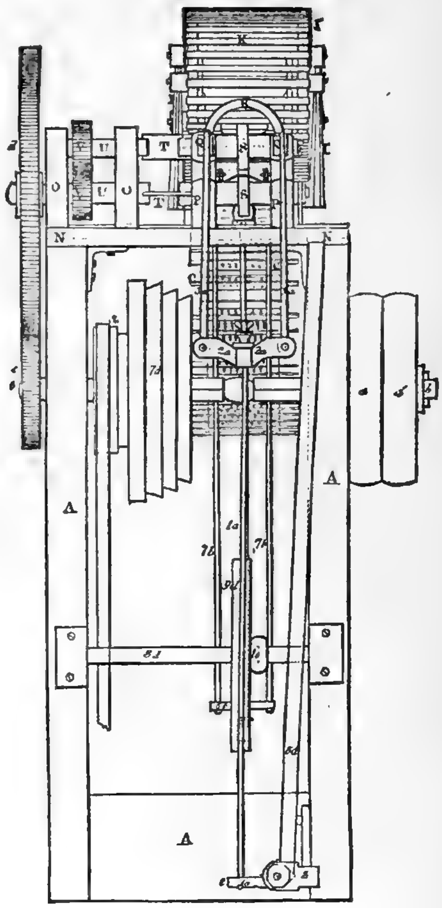
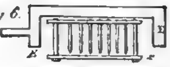


Fig. 7.

Fig. 6.



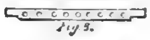


Fig. 8.

Fig. 12.

Fig. 11.

Fig. 10.

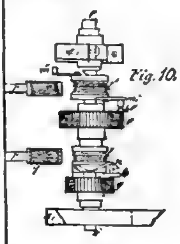


Fig. 13.

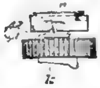
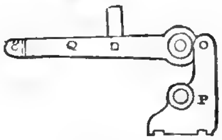


Fig. 9.



Let us now suppose a roving of hemp to be passed into the tunnel L, and the pulley B to be turned in the direction of the arrow; the bobbins lying between the rows of hatchel-teeth must be carried along with the hatchel-belt; and as some of the bobbins, by their connection, in forming the bobbin-belt, constantly pass out of the hatchel-belt on the right, so others constantly pass into it on the left. When, therefore, the roving of hemp, passing into the tunnel L, meets the hatchel-points, it is pressed between them by the bobbins, and passes along in the hatchel-belt until it arrives near the end F′ of the rails F F′. Now, as the rails pass beyond the pulley B′, to the right, and as the clearers (see Fig. 6), as has been before described, pass on the top of the rails, it is evident that they will be raised upwards, upon the hatchel-points; and as the roving of hemp is always above them, this also must be lifted out of those points. Suppose that the end of the roving be then passed through the gatherer X, and that it be made to enter between the drawing-rollers. If the drawing-rollers are now turned faster than the hatchel-belt carrying the roving, the roving must be drawn out through the hatchel-points by the rollers, forming a filament as much smaller than the original roving as the rollers move faster than the hatchel-belt. If, however, the relative motions be constant, then these proportions will be true only when the mean size of the filament is compared with the mean size of the roving; for the roving is not supposed to be of equal size throughout, and, moreover, the ends of the fibres of hemp cannot be distributed at equal distances in it; hence more of these ends will be taken into the rollers together at some times than at others. Now when many ends meet the rollers together, many fibres must be drawn out of the hatchel together and the filament be made larger than at other places, where the ends of fibres, by being distributed in the roving at greater distances, meet the rollers less frequently. To prevent as much as possible this inequality in the filament, I use the apparatus now to be described, which I call the *regulator* and the *comb*.

A small cast-iron frame, *e e e* (Fig. 3), is fixed upon the wooden frame A A. The shaft *f f* is made to run in proper centres fixed in the frame *e e*, and placed upon it are the wheels g, g' [the shaft, with its connections, is drawn separate from the frame in Fig. 10]. These wheels are bored with a round hole, and turn freely upon the shaft *f f*, except as hereinafter described, but are prevented by proper collars from slipping in the direction of the length of the shaft. A second shaft, *h h*, is made to run in centres upon the same frame, *e e*, parallel to *f f*. The wheels i, i', are fixed firmly on the shaft *h h*. The wheels g and i' have fifty teeth each, the wheels g' and i have seventy teeth each, and the diameters of all the wheels are in proportion to the number of teeth. [In the figure, g' is drawn too large, and i too small.] The teeth of g play into those of i, and the teeth of g' into those of i'.

There are two locking-pins, or catches, k, k' (Fig. 3), fixed upon the wheels g, g'. l, l' (Fig. 10) are two clutch-boxes placed upon the shaft *f f*. These clutch-boxes are free to slide in the direction of the axis of the shaft; but in the shaft are fixed pins which project into a groove cut lengthwise on the inside of each clutch-box so that the clutch-box must always turn with the shaft. Several parallel grooves are turned in the body of each clutch-box. A slide-bar, *o o*, is placed on the frame *e e*, parallel with the shafts *h h* and *f f*, and is capable of being moved in the direction of its length, and in that direction only. Two arms, *p p*, are screwed upon the top of this slide-bar, and pass from it towards the shaft *f f*, and terminate directly over the clutch-boxes *l l*, that is, one arm over each clutch-box. There are fixed to the under side of each arm, *p*, *p*, metal blocks or boxes, *q q*, which pass down to the clutch-boxes. The under sides of *q q* are formed in the shape of a hollow cylinder, and are grooved so as to embrace the clutch-boxes upon the parallel grooves formed upon them through about one third of their circumference. [Figure 11 shows the slide-bar *o o* and arms *p p*, separate from the other works. The figure represents the under side of these parts.] It will be seen that, when the shaft *f f* is in motion, the clutch-boxes, by reason of the pin in the shaft and the longitudinal groove in the clutch-boxes, must move also, but the wheels g and g', being loose on the shaft *f f*, do not move. On each clutch-box is fixed a locking-pin, m and n, and also on each of the wheels g and g' a locking-pin, k and k'; now if these locking-pins on the clutch-box and those on the wheels g and g' are brought in contact, these wheels must move with the shaft *f f*, and as they gear with the wheels i, i', fixed on the shaft *h h*, the shaft must move also. Now the clutch-boxes are connected by the two arms *p p* with the slide-bar *o o*, and are moved with it to the right and left (Figs. 3 and 5), so locking and unlocking with the wheels *g* and *g'*. The slide-bar *o o* is made to move by the following described apparatus. A long shaft or axle, *r r* (Fig. 3), passes horizontally from under the slide-bar *o o* to the right hand, as seen in the drawings, until it projects beyond the frame A A. [In Fig. 2 this shaft is supposed to be broken off under the drawing-roller S S, at the right hand of the drawing-frame, and the left-hand part removed.] *r r r* is hung in centres which are fixed in the iron bearing, *s s*, at the extreme right of Figs. 1, 3, and 4. 6*d* is an iron brace to keep *s* from springing. The arm *t* passes horizontally from the right end of *r r*, and the arm *t'* rises vertically from the other end (Fig. 5), directly under the slide-bar *o o*. V is a bent lever, the fulcrum being a pin which passes through and unites it to the bearing W, which is fixed to the frame A A. The vertical arm of the lever V is fixed in the bottom of the slide-bar, and the horizontal arm of the same lever is connected with the weight, Y, as seen in Fig. 5, and also in dotted lines in Fig. 1. This lever and weight draws the slide-bar constantly to the right. The rod 1*a* 1*a* (Fig. 4) is united to the horizontal arm *t* on the shaft *r r* by a movable joint, and passes upward to the cross-bar 2*a* 2*a* (Figs. 1 and 4). The rod 1*a* passes through the middle of 2*a*, and receives a thumb-nut upon its top. The connecting rods 3*a* 3*a* pass from the ends of the cross-bar 2*a*, and are united by pins to the levers Q Q, one rod uniting to each lever. It is in holes in these levers that the upper roller, S, runs. The lever Q is seen detached in Fig. 9.

In addition to the parts heretofore described as connected with the shaft *f f* there is placed upon that shaft the *star-wheel*, 4*a* (Fig. 5), a side view or elevation of which is given detached in Fig. 12, and on the shaft of Fig. 10 and Fig. 3. The star-wheel is fitted to the shaft *f f* like the wheels *g*, *g'*, the shaft passing through a round hole in its centre, and proper collars are fixed to the shaft, on each side of it, to prevent it from sliding in the direction of the shaft. A wooden lever, 6*a* 6*a* (Fig. 3), passes from a point near the star-wheel horizontally to a point directly under the gatherer, X (Fig. 1). This lever turns on a fulcrum in the pillar 7*a*, fixed to the frame A. The other end of the lever is just capable of reaching the star-wheel, which throws it up whenever the star-wheel is turned round for that purpose. 4*b* (Fig. 5) is a little click attached to the frame *e e*, which passes up through a hole or slot in the slide-bar by the side of the lever 6*a*, and slips under its end whenever it is caught by the star-wheel above the top of the click, and holds it up. But this is only done so long as the slide-bar carries the clutch-box *l* so far to the left that the catch *m'* no longer touches the point of the star-wheel. The click is so arranged as to slip out from under the end of the lever 6*a*, which is pulled down by the weight, 5*b* (Fig. 1), attached to it. To the top of the lever 6*a*, near its right end, as seen in Figs. 1 and 3, is united by a hinge-joint the cross-bar 6*b*, to each end of which are fixed rods, 7*b* 7*b*, which pass directly upwards through guide-holes in the piece of cast iron, W, each side of the gatherer, X, and on the outside of the same, and are fixed by their tops to the comb 8*b*. The comb is formed of several rows of iron teeth riveted to an iron plate. The several rows of teeth are directly over the slits in the top of the gatherer, X, which have been before described, and when forced downwards pass through these slits into the roving of hemp which is in the gatherer. Two cast iron pillars, 9*b*, at the lower right-hand corner of Fig. 1, are fixed to the frame A A, and rise above and on each side of the lever 6*a*. A small lever, 1*c*, is placed between the pillars 9*b*, directly over the lever 6*a*, and is hung upon a pin which passes through 9*b* 9*b* near their tops, and through 1*c*. This pin forms a fulcrum or axis on which 1*c* turns. To the right end of 1*c*, as seen in Figs. 1 and 3, there is connected, by a movable joint, the rod 2*c*, which passes directly upwards through guide-holes in the piece of cast iron W, and the bottom of the gatherer. The left end of the lever 1*c*, as seen in Figs. 1 and 3, is connected with the lever 6*a* by hooks. It will readily be perceived by this description and the figures, that, when the right end of the lever 6*a* is depressed, the right end of 1*c* will be elevated and carry the rod 2*c* upwards, which will lift the false bottom, before described, of the gatherer, the teeth of the comb passing, at the same time, through the slits made in the false bottom of the gatherer. Upon the shaft *b b* (Fig. 4) is fixed the pulley 3*c*, from which a belt passes to and over the pulley 4*c* (Fig. 1), fixed upon the shaft *f f* (Fig. 3). Upon the shaft *h h* (Fig. 3) is fixed the pulley 5*c* (Fig. 1), and from the pulley 5*c* a belt passes to and over the pulley 6*c*, which is fixed upon the shaft 7*c*, which, by inspection of Fig. 1, will be seen to drive the pulley B, which moves the hatchel-belt C.

To understand the operation of the regulator and comb, we will suppose that the roving of hemp entering at L (Fig. 1) has been carried in the hatchel-belt to the drawing-rollers S S (Fig. 4), moving with a constant rotary motion, and that the wheels and pinions move the shaft *f f* (Fig. 10); then if the filament between the rollers is of the right size, as arranged by the thumb-nut 2*a* (Fig. 4), the catch, *m m′* (Fig. 10), will not engage the wheels *g* and *g′*, and there will be no motion in the pulley B, nor of the hatchel-belt, and no hemp presented to the drawing-rollers S S, and the filament will become small. Then the upper drawing-roller running in the levers Q Q (Fig. 1) will fall, and the rod 1*a* will fall, and the rod *r r* will roll, carrying with it the arm *t′*, which with the weight *y* will draw the slide-bar *o o* (Figs. 5 and 10) to the right, and the catch *m m′* on the clutch-boxes (which are always in motion, in connection with the shaft *f f*) will engage the wheels *g* and *i*, which will revolve and give motion, through the connecting pulleys 5*c*, 6*c*, and 8*c*, to the pulley B, which will put the hatchel-belt in motion and advance the roving to the drawing-rollers until the filament is sufficiently large, when the rod 1*a* will rise and the slide-bar *o o* move to the left, and the catch *m m′* no longer drive the wheel *g*, and the further advance of the roving cease. If, however, the filament does not increase, but diminishes, then the rollers S S and the levers Q Q fall still more, the slide-bar moves still farther to the right, and the catch *m′* engages the pin *k′* upon the wheel *g′* and carries it round with it. Now, as the wheel *g′* is larger than the wheel *g*, and the wheel *i′* is smaller than the wheel *i*, the shaft *h* and the pulley 5*c* will, through the successive pulleys and pinions, drive the pulley B faster, and the fibres of roving on the hatchel-belt will reach the drawing-rollers more frequently.

If now the filament is too large, the upper roller rises, and, by the connections already described, the shaft *r r* rolls and its vertical arm *t′* moves the slide-bar to the left, and the star-wheel raises the end of the lever 6*a*, and, the opposite end being depressed, brings down the teeth of the comb 8*b* (Fig. 1) into the roving, at the same time that the right end of the lever 1*c* rises and the rod 2*c* forces up the false bottom of the gatherer X and impedes the passage of the fibres of the roving to the drawing-rollers, while a portion of those already between them are broken off until the roving is reduced to the proper size, when the comb will rise, the false bottom fall, and the roving, no longer impeded, will again move on.

Fig. 14 represents an elevation of the bobbin-frame of the Gypsey by which the filament is twisted and wound up; and Fig. 16, an elevation as seen in the end of the drawing-frame. 6*e* 6*e* 6*e* is the wooden frame of the bobbin-frame. The flyer is shown, 1*f* 1*f*. 2*f* 2*f* are sheaves over which the yarn runs to be wound on the bobbin, 5*f*. The bobbin-spindle, 3*f*, runs in a box upon the frame, 6*e*, and on a bar marked 4*f*, which is on the base of the flyer and crosses from one side to the other, and can slide upon these bars in the direction of their length. The spindle passes through the hollow centre of the right gudgeon of the flyer, as seen in Fig. 14; the hole through the gudgeon being somewhat larger than the spindle. The pulley 6*f* is fixed to the bobbin-spindle, and the pulley 7*f* is fixed to the flyer, and the bands of both pulleys run over the drum 9*f*, that end of it over which the band 7*f* runs being larger than the rest of the drum, by which arrangement the flyer is driven faster than the bobbins, and thus winds up the yarn upon it. When, by the accumulation of the yarn on the bobbin, its circumference is increased, the difference between the greater circumference and the revolutions of the flyer is provided for by the slight tension of the belt which passes over the drum 9*f* to the pulley 6*f*, by which it is made to slip in some degree by the pulling of the yarn itself upon the bobbin from the constant tending of the flyer to wind it up.

To distribute the yarn equally upon the bobbin, it is necessary that it should move alternately through a space equal to its length. To do this, a collar, 3*g*, is placed upon the spindle 3*f*. This collar runs in a stud, 4*g*, which stands upon a slide, 5*g*. This slide can be moved in the direction of its length, its right end resting in a proper box in the frame 6*e*. Two straps pass from buckles to the slide 5*g* (Fig. 14), over the top of the pulley 6*g* in opposite directions, and are fastened to the periphery of the pulley on different sides of the same. A similar arrangement connects *f g* with the pulley 8*g*. 2*h* is a heart-wheel, which moves 7*g* back and forth. It will be seen that, when the heart-wheel moves the slides

7*g* and 5*g*, and the stud 4*g* standing upon it, the spindle 3*f* and the pulley 6*f* also move back and forth. The band on the pulley 6*f* at the same time alternately traverses the drum 9*f*.

Fig. 14.

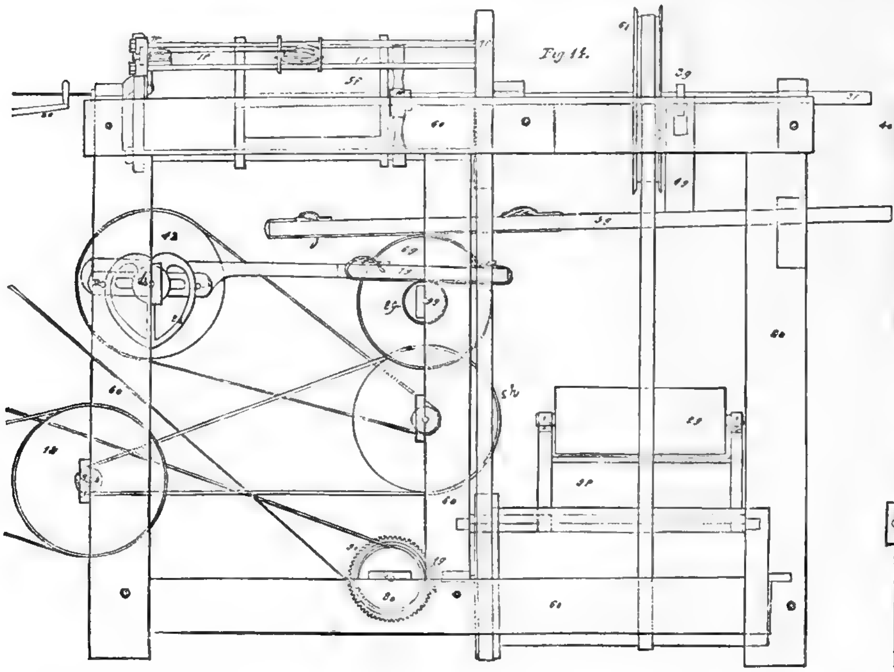
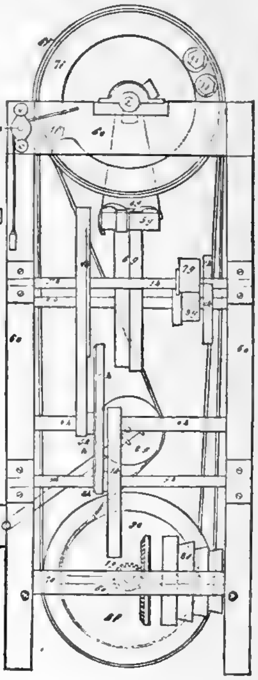


Fig. 16.



To stop the machine when the yarn breaks, an iron rod, 2*e* (Figs. 1 and 2), is hung at one end by a hinge-joint to the frame A A, and runs horizontally till it nearly meets the bobbin-frame, where it is bent into a sort of hook, which is drawn against the side of the yarn by a weight passing over a pulley, 4*e*. On the rod 2*e* is a fork, 2*c*, through which passes the main belt *a* (Fig. 2) that drives the machine. When the yarn breaks, the iron rod with the fork drawn by the weight shifts the belt from the driving pulley to the loose pulley *a*′, and the machine stops.

II. — See page 403.

REPORT OF EXPERIMENTS ON BOSTON AND WORCESTER RAILROAD.

To Hon. Nathan Hale, *President of the Boston and Worcester Railroad Company:* —

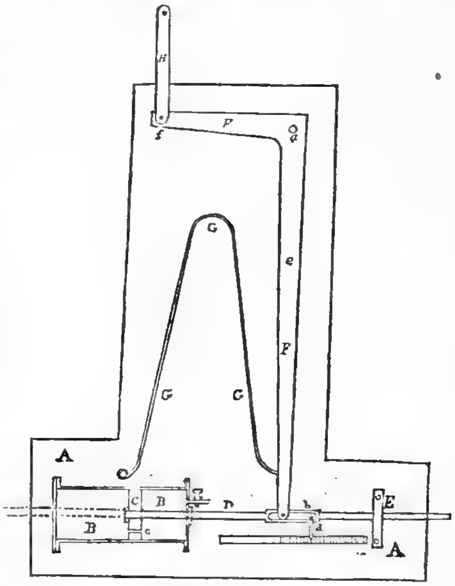
Sir, — After a delay of several months, from the pressure of other avocations, I have completed the computation from the notes of the experiments made, at your request, to determine the resistance of the cars, and various other facts connected with the motion of loads over railways, and I now beg leave to present to you an account of the experiments, with the results obtained.

The experiments were ordered for the especial purpose of determining the effect of the apparatus called a "Sparker," invented by J. F. Curtis, Esq., the object of which is to obviate the annoyance, and even danger, which arise from the sparks which pass from the fire of the locomotive engine, and, falling about the train of cars, often enter them and set fire to the clothes and occasion other inconveniences to the passengers. The free egress of the sparks from the chimney of the locomotive engine has been in some degree prevented by the application of a large cap of wire gauze over its top. It has not been found practicable, however, to make and use this with openings sufficiently contracted to prevent the escape of the smaller sparks, and the apparatus of Mr. Curtis is in addition to the gauze cap as ordinarily used. It consists of a round plate of iron fixed within the cap and directly over the chimney. It is formed a little convex upon its under side, so as to deflect the sparks which are blown against it outwards and downwards through the stream of smoke which is passing by its edges, that they may fall a little upon the outside of the top of the chimney, where they are collected in a cavity formed between the bottom of the cap and the chimney which projects into it. From this they are conveyed by a small pipe down outside of the chimney, and drop from its open end near the ground.

The effect of the instrument in preventing the egress of the sparks from the chimney is not, I believe, doubted by any one who has witnessed its operation; but as an opinion has been formed by several of the operative engineers that the sparker diminishes the effective power of the engine, it was decided that the truth of this opinion should be tested by experiments. As these experiments would require that the engine should run over a considerable extent of the road, and that the weight of the load, resistance, and velocity should be observed, it was thought advisable to arrange the observations so as to obtain, in addition to a decision of the question concerning the sparker, facts for the solution of other questions; such as the comparative powers of engines of different dimensions and forms of construction; the comparative power of the same engine, using steam of a given elastic force, when running at different velocities; the quantity of wood required to produce a given power; the resistance of the load when passing upon a horizontal plane and upon ascents of different inclinations, and likewise the effects of the curves of the railway in increasing the resistance, and any other facts important to the construction, arrangement, or management of railroads or locomotive engines.

To make experiments which should give satisfactory conclusions in the cases above recited, it seemed to me important, first of all, to obtain an instrument by which the force of the engine in drawing the load, or rather the resistance of the load, should be accurately measured. No dynamometer had as yet, to my knowledge, been constructed, which, when applied to an engine and its train, was not subject to such wide and rapid vibrations as to render it impossible to determine the force upon it at any instant of time. To obviate this difficulty, I contrived, and had constructed, an instrument as herein shown.*

A A, a strong plate of cast iron, upon the face of which is fixed B B, a cylinder, shown in section, accurately bored. C, a piston one fiftieth of an inch less in diameter than the cylinder, and pierced with the small hole *c*, one eighth of an inch in diameter. D, piston rod, its top guided in the box E. F, a bent lever moving upon the pin *a*, as a fulcrum, and its horizontal arm attached to the piston rod by the connecting jointed rod *b*. G G G, a powerful spring tending to raise the horizontal arm of the lever F, and consequently the piston. H, a connecting rod to be united to the tender of the engine. *d*, an index fixed to the upper part of the piston rod, which points upon the scale, marked 10, 20, 30, 40, &c., to the force in pounds which is at any time acting upon the connecting rod H. To mark or divide this scale weights are hung upon the horizontal arm of the lever F, the plate A A being in a vertical plane, at *e*, being the same distance from the fulcrum *a* with the pin *f*. The depression of the arm by the weights so placed will of course be



TREADWELL'S DYNAMOMETER.

---

* Count Pambour (*Traité Théorique et Pratique des Machines Locomotives*, pp. 101, 108, Paris, 1835) found the same difficulty with all circular dynamometers, and abandoned that mode of determining resistance on railroads. He substituted as a method of measuring these resistances, the descent of a train of cars along two inclined planes, the inclination of the second

equal to the depression which would be produced by a force equal to such weight acting horizontally through H, in a direction from right to left.

When this instrument is used, the plate A A A is fixed firmly upon a car, its face in a vertical plane, and the cylinder B B filled with oil through the stop-cock on the top, while the piston is at the bottom. For greater accuracy in the measurement, the piston rod could pass through the bottom of the cylinder in a close collar, so that the contents of the cylinder would be constant. This addition to the rod is indicated by the dotted line. The rod H is then attached to the tender of the locomotive. As the piston passes downward, the oil beneath it must flow through the small hole at *c*, and likewise between the walls of the cylinder and the piston; the resistance to its passage is in proportion to the square of its velocity. Hence the arm cannot be depressed so suddenly beyond the mean pressure of the draft of the engine; its vibrations are controlled by the passage of the oil at the same time that the resistance to the slow passage of the oil is very inconsiderable. One hundredth of an inch between the side of the piston and the cylinder, and one eighth of an inch diameter of the hole in the piston, gave a sufficiently slow movement, even with a weight of two or three hundred pounds on the top of the piston rod. Any force required to drive the oil through the narrow apertures has no practical influence on the result.

The road on which these experiments were made comprises 20½ miles of the eastern end of the Boston and Worcester road (now Boston and Albany); namely, from the depot in Boston to that in Framingham, and consists of twenty-six different planes, horizontal and inclined, no inclination exceeding thirty feet in a mile, and the longest inclination being 13,200 feet. There are, moreover, curves in its course, the radii varying from   to   feet. The rails are common English edge rails of equal depth, of wrought iron, and weighing fifty-six pounds per yard; they are fixed in iron chairs on wooden sleepers [ties]. Immediately preceding the time of the experiment the rails had been adjusted, and the road was in good order throughout.

The following enumeration exhibits, under their respective names, the dimensions of the most important parts of the locomotive engines used in the experiments.

	Meteor.	Mercury.	Lion.
Number of cylinders	2	2	2
Diameter of cylinders	9 in.	10 in.	11 in.
Length of stroke	16 in.	16 in.	16 in.
Steam way opened by the slide valve.			
Length of boilers and tubes	6 ft. 6½ in.	7 ft. 4 in.	7 ft. 8½ in.
Number of tubes	62	59	76
Diameter of tubes	1½ in.	1½ in.	2 in.
Area of tubes inside	151 sq. ft.	162 sq. ft.	291 sq. ft.
Area of fire grate	5.2 sq. ft.	5.8 sq. ft.	7.6 sq. ft.
Area of boiler exposed to radiant heat	31.9 sq. ft.	33.4 sq. ft.	36.3 sq. ft.
Weight of the engine when full of water	13,654 lb.	16,985 lb.	22,531 lb.
Diameter of hind and driving wheel	5 ft.	5 ft.	5 ft.
Diameter of journals (gudgeons)	$2\frac{27}{32}$ in.	$2\frac{1}{8}$ in.	$4\frac{3}{4}$ in.
Diameter of forward wheels	42 in.	42 in.	42 in.
Diameter of journals of forward wheels	$2\frac{27}{32}$ in.	$2\frac{9}{16}$ in.	$4\frac{3}{4}$ in.
Height of chimneys	12 ft. 6 in.	12 ft. 6 in.	12 ft. 6 in.
Diameter of chimneys	12 in.	12 in.	13 in.

The same tender was used in all the experiments. The weight of this when empty was 5,680 lb.; it held 5,830 lb. of water; consequently, when full, its weight was 11,510 lb.

being less than that of the first, and noting the distance run by the force of gravity. He found the value of the friction, and other resistances, to be equal to the weight multiplied by the total height the train has descended, divided by the distance run. A number of experiments on the Liverpool and Manchester railroad, with weights averaging 60.5 tons, and a velocity of ten or twelve miles an hour, gave an average resistance of 8.5 pounds to the ton of 2,240 pounds. — W.

The cars upon which the loads were placed were of the common form and size, the bodies resting upon springs. The wheels were 3 feet in diameter and the journals (gudgeons) 1⅞ inches in diameter.

With this account of the apparatus, I shall proceed to give an account of six experiments made with the engines before described.

1. Friday, October 14, 1836. Experiment made with the Mercury, with the sparker on the engine, from the depot in Boston to Framingham, 20½ miles.

Load or Train.

Tender No. 4, to which the dynamometer was attached from the first car.

10 cars loaded with iron nails	Weight, 81,843 lb.
1 car loaded with stone	9,210
1 car loaded with some iron, and carrying apparatus and four persons	5,050
	Whole weight, 96,103 lb.

One car was left at the ascent between the 11th and 12th mile, and is therefore accounted at half its weight carried through. On the return the weight of the car is deducted, which leaves the load on the return . . . . 91,795 lb.

Out.			Return.			Remarks.
	Time.	Mean Draft.		Time.	Mean Draft.	
	h. m. s.	lb		h. m. s.	lb.	
To 1 mile post	5 30	798	To 20 mile post	2 45	577	Wind strong from the west, or against the train, in its course from Boston to Framingham.
" 2 "	6 0	633	" 19 "	3 15	280	
" 3 "	3 30	616	" 18 "	2 45	297	
" 4 "	2 15	440	" 17 "	3 45	681	
" 5 "	2 45	390	" 16 "	3 40	726	
" 6 "	4 0	662	" 15 "	3 15	292	
" 7 "	5 30	490	" 14 "	3 5	0	
" 8 "	4 30	597	" 13 "	6 0	640	
" 9 "	3 15	489	" 12 "	3 30	276	Engine stopped 8 minutes between the 11th and 12th mile, did not draw the load. Uncoupled to turn out to get water. Threw off one car, and then the engine drew the remaining load up the plane. The time of this stop deducted from the whole time of passing from 11th to 12th mile.
" 10 "	3 45	552	" 11 "	3 0	60	
" 11 "	4 15	675	" 10 "	3 15	96	
" 12 "	12 15	795	" 9 "	2 45	315	
" 13 "	6 30	705	" 8 "	2 45	360	
" 14 "	2 45	442	" 7 "	2 40	369	
" 15 "	3 15	450	" 6 "	3 25	205	
" 16 "	4 30	662	" 5 "	2 40	99	
" 17 "	4 45	238	" 4 "	4 5	258	
" 18 "	3 15	172	" 3 "	2 45	337	
" 19 "	3 10	520	" 2 "	3 0	297	
" 20 "	3 35	424	" 1 "	3 25	250	
To Depot at Framingham	2 0	126	To Depot in Boston	4 0	109	
	91 15	10,876		69 45	6,524	
Time	1 31 15	518	Time	1 9 45	310.6	

Wood used, being pine of ordinary quality. Out, 83 cubic feet, measured as ordinarily piled. Return, 60 cubic feet. The wood required to get up the steam not included in either case, either in this or the experiments afterwards made.

Water used. Out, 53.4 cubic feet. Return, 42.5 cubic feet.

Wood used to evaporate 1 cubic foot of water. Out, 1.55 cubic feet. Return, 1.41 cubic feet.

The method pursued in noting the velocity and force of the draft, or traction, was as follows. An assistant marked at every thirty seconds the place of the index of the dynamometer. The time of passing each mile-post was observed and set down by myself. These accounts were afterwards compared together, and the mean force of the draft, as shown by the assistant's minutes, cast for each mile. The velocity was taken from my own minutes. It may seem to have been a neglect that no regular entry was made of the elastic force of the steam. But the imperfection of the common safety-valve for measuring this force is well known, being in fact wholly fallacious, and, moreover, the object of immediate inquiry did not render a constant knowledge of this force necessary. I may remark that the steam was kept at about 60 pounds to the inch, as shown by the safety-valve.

To find in these experiments the resistance from friction, and all sources other than that derived from the inclination of the road, we may consider the whole road as forming one plane, and take the level of Framingham above that of Boston as giving its inclination. The difference in these levels is 160 feet, and the distance from one to the other 20½ miles, or 108,240 feet. Hence $\frac{108240}{160} = 676$, or a plane rising one foot in 676 would unite the two levels, and the force required merely to elevate any load over such a plane would be equal to $\frac{1}{676}$th part of the weight of the load.

To apply this to the foregoing experiments, the load being 96,103 lb., we have $\frac{96103}{676} = 142.1$ lb. of the draft from elevating the load, and the mean force of the whole traction as shown by the dynamometer was 518 lb.; then $518 - 142.1 = 375.9$ lb., as the resistance from friction and all other sources than that of elevating the load. Again, $\frac{96103}{375.9} = 255$, or the traction from friction was equal to $\frac{1}{255}$th part of the load. Hence the resistance from this source was 8.78 lb. to every ton of 2,240 lb. of load.

By the same method the resistance from friction may be found on the return; but as the load *descended* through a space equal to $\frac{1}{676}$th part of the space passed through, we must add $\frac{1}{676}$th part of the weight of the load to the mean force of traction, as shown by the dynamometer, to obtain the resistance of the friction. We have, then, the load being 91,795 lb. for the return, $\frac{91795}{676} = 135.8$ lb. for the effect of the tendency of the load itself to descend. Mean draft on the dynamometer 310.6 lb. Then $135.8 + 310.6 = 446.4$ lb., the resistance of the friction. Again, $\frac{91795}{446.4} = 206$, or the resistance from friction was equal to 206 lb. of the load. Hence on a level, according to this experiment, the force of traction was 10.87 lb. for each ton of 2,240 lb.

It will be observed that in all the trials, with a single exception, the traction on the return, or down the plane, when reduced to a level, as in the foregoing example, was greater than the traction out or up the plane. This small discrepancy is to be attributed to the fact that the dynamometer did not indicate negative quantities, which it might easily be made to do, and on some of the steep descents the train bore hard upon the tender and the engine; for the friction of these being greater than that of the cars compared with their weight, a portion of the descending force of the latter was transmitted to them through the dynamometer, where, if it had been measured as a negative quantity, I have no doubt but the experiments in the two directions would have shown a much more exact correspondence. From this statement it will be perceived that the resistance of the friction as deduced from the experiments made up the plane is to be considered as the true measure, and should be taken as such by any one who is desirous of obtaining the absolute amount of this resistance.

2. Experiment made, October 15, with the Mercury, without the sparker, from the depot in Boston to Framingham.

LOAD OR TRAIN.

Tender No. 4.		
9 cars loaded with iron rails	Weight,	77,535 lb.
1 car loaded with stone		9,210
1 car carrying apparatus and 4 persons		5,050
	Whole weight,	91,795 lb.

Wood used, being pine of ordinary quality. Out, 67 cubic feet measured as ordinarily piled. Return, 43.7 cubic feet.

Water used. Out, 52 cubic feet. Return, 40.6 cubic feet.

Wood required to evaporate one cubic foot of water. Out, 1.27 cubic feet. Return, 1.20 cubic feet.

OUT.			RETURN.			Remarks.
	Time.	Mean Draft.		Time.	Mean Draft.	
	h. m. s.	lb.		h. m. s	*lb.*	
To 1 mile post	4 0	795	To 20 mile post	3 0	655	
" 2 "	3 15	532	" 19 "	3 45	442	
" 3 "	2 15	465	" 18 "	2 16	351	
" 4 "	3 20	535	" 17 "	3 30	675	
" 5 "	2 25	463	" 16 "	4 0	759	
" 6 "	3 35	616	" 15 "	2 45	112	
" 7 "	4 10	736	" 14 "	4 30	324	
" 8 "	3 35	631	" 13 "	3 40	292	
" 9 "	2 40	477	" 12 "	3 50	469	
" 10 "	3 30	516	" 11 "	2 30	18	
" 11 "	4 0	661	" 10 "	2 50	153	
" 12 "	6 0	317	" 9 "	2 40	360	
" 13 "	5 20	769	" 8 "	2 50	547	
" 14 "	8 5	565	" 7 "	2 40	459	
" 15 "	2 45	576	" 6 "	3 0	247	
" 16 "	4 15	744	" 5 "	2 80	225	
" 17 "	4 0	517	" 4 "	3 0	423	
" 18 "	3 0	127	" 3 "	2 30	372	
" 19 "	3 30	517	" 2 "	2 45	270	
" 20 "	3 0	442	" 1 "	2 30	367	
To Depot in Framingham	2 45	270	To Depot in Boston	3 15	153	
	74 55	11,951		64 15	7,673	
Time	1 14 55	569	Time . . .	1 4 15	365	

Following the method pointed out in the preceding experiment for finding the resistance from friction, the load being 91,795 lb., we have: —

Out. $\frac{91795}{676} = 135.8$ lb. of the resistance shown by the dynamometer from elevating the load. Mean draft, $569 - 135.8 = 433.2$ resistance from friction, and $\frac{91795}{433.2} = 211.9$; or draft when reduced for a level $\frac{10}{2119}$ths of the load. Hence 10.57 lb. required to draw 1 ton of 2,240 lb.

Return. $\frac{91795}{676} = 135.8$ lb., the tendency of the load to descend which was not shown by the dynamometer, Mean draft shown by the dynamometer $865 \times 135.8 = 500.8$ lb. resistance from friction, and $\frac{91795}{500.8} = 183.3$, or draft when reduced for a level $\frac{10}{1833}$ds of the load. Hence 12.2 lb. required to draw 1 ton of 2,240 lb.

3. Experiment made, October 28, with the Meteor, withthe sparker on the engine, from the depot in Boston to Framingham.

LOAD OR TRAIN.

Tender No. 4.		
8 cars loaded with iron rails	Weight,	68,920 lb.
1 car loaded with stone		9,210
1 car carrying apparatus and 3 persons		4,900
	Whole weight,	83,030 lb.

Wood used, being pine of ordinary quality. Out, 61.3 cubic feet. Return, 40 cubic feet.

Water used. Out, 37.55 cubic feet. Return. 31.35 cubic feet.

Wood used to evaporate one cubic foot of water. Out, 1.63 cubic feet. Return, 1.27 cubic feet.

Following the method before denoted for finding the resistance from friction, the load being 83,030 lb., we have: —

Out. $\frac{83030}{676} = 122\ 3$ lb. of the resistance shown by the dynamometer from elevating the load. Mean draft, $433.5 - 122.8 = 310.7$ lb. resistance from friction, and $\frac{83030}{310.7} = 267$; or draft when reduced to a level $\frac{1}{267}$th of the load. Hence 8.33 lb. required to draw one ton of 2,240 lb.

Return. $\frac{83030}{676} = 122.3$ lb., the tendency of the load to descend which was not shown by the dynamometer. Mean draft shown by the dynamometer $231.4 + 122.8 = 354.2$ lb. resistance from friction, and $\frac{83030}{354.2} = 234.4$, or draft from friction when reduced for a level $\frac{10}{2344}$ths of the load. Hence 9.55 lb. required to draw one ton of 2,240 lb.

Out.			Return.			Remarks.
	Time.	Mean Draft.		Time.	Mean Draft.	
	h. m. s.	lb.		h. m. s.	lb.	
To 1 mile post	8 25	501	To 20 mile post	4 0	391	
" 2 "	8 55	405	" 19 "	3 35	253	Wind strong from the west.
" 3 "	8 35	382	" 18 "	3 5	195	
" 4 "	3 30	456	" 17 "	4 35	514	
" 5 "	3 20	393	" 16 "	13 40	679	
" 6 "	4 0	438	" 15 "	3 0	30	
" 7 "	4 40	508	" 14 "	3 0	142	
" 8 "	3 5	510	" 13 "	2 45	360	
" 9 "	3 4	225	" 12 "	3 25	45	
" 10 "	4 26	427	" 11 "	3 5	0	
" 11 "	11 28	622	" 10 "	2 50	112	
" 12 "	17 37	727	" 9 "	3 15	180	
" 13 "	8 10	654	" 8 "	5 2	405	
" 14 "	3 55	326	" 7 "	3 10	231	
" 15 "	4 0	411	" 6 "	3 28	169	
" 16 "	6 35	618	" 5 "	3 40	174	
" 17 "	5 45	403	" 4 "	3 20	255	
" 18 "	3 0	108	" 3 "	3 0	217	
" 19 "	3 15	424	" 2 "	3 35	192	
" 20 "	3 5	420	" 1 "	3 35	180	
To Depot in Framingham	2 25	135	To Depot in Boston	4 20	191	
	106 45	9,103		83 25	4,360	
Time	1 46 45	4285	Time	1 23 25	231.4	

4. Experiment made, October 29, with the Meteor, without the sparker, from the depot in Boston to Framingham.

Out.			Return.			Remarks.
	Time.	Mean Draft.		Time.	Mean Draft.	
	h. m. s.	lb		h. m. s.	lb	
To 1 mile post	3 45	480	To 20 mile post	2 30	532	
" 2 "	3 30	525	" 19 "	2 45	285	
" 3 "	3 5	465	" 18 "	2 50	126	
" 4 "	3 25	489	" 17 "	3 15	507	
" 5 "	2 40	412	" 16 "	5 0	527	
" 6 "	3 50	432	" 15 "	2 50	18	
" 7 "	4 25	505	" 14 "	2 50	99	
" 8 "	3 40	515	" 13 "	2 40	367	
" 9 "	3 10	300	" 12 "	3 0	120	
" 10 "	4 20	514	" 11 "	2 30	0	
" 11 "	4 30	585	" 10 "	3 0	63	
" 12 "	10 15	672	" 9 "	3 0	120	
" 13 "	7 55	615	" 8 "	3 10	255	
" 14 "	3 25	450	" 7 "	3 0	322	
" 15 "	3 55	472	" 6 "	3 5	90	
" 16 "	5 55	623	" 5 "	2 50	142	
" 17 "	4 50	391	" 4 "	2 55	236	
" 18 "	3 20	105	" 3 "	2 35	234	
" 19 "	3 30	510	" 2 "	3 10	225	
" 20 "	3 25	430	" 1 "	3 35	195	
To Depot in Framingham	2 50	186	To Depot in Boston	3 30	0	
	89 40	9,836		63 0	4,463	
Time	1 29 40	468.4	Time	1 3 0	212.5	

LOAD OR TRAIN.

Tender as before.	
3 cars loaded with iron rails	Weight, 68,920 lb.
1 car loaded with stone	9,210
1 car carrying apparatus and 3 persons	4,900
	Whole weight, 83,030 lb.

Wood used, being pine of ordinary quality. Out, 42 cubic feet. Return, 20.5 cubic feet.

Water used. Out, 39.42 cubic feet. Return, 20.13 cubic feet.

Wood required to evaporate one cubic foot of water. Out, 1.06 cubic feet. Return, 1.02 cubic feet.

Following the former method for finding the resistance from friction, the load being 83,030 lb., we have: —

Out. $\frac{83030}{676} = 122.8$ lb. of the resistance shown by the dynamometer from elevating the load; mean draft $468.4 - 122.8 = 345.6$ lb. of resistance from friction, and $\frac{83030}{345.6} = 240.2$; or draft when reduced to a level $\frac{10}{2402}$ds of the load. Hence 9.32 lb. required to draw one ton of 2,240 lb.

Return. $\frac{83030}{676} = 122.8$ lb., the tendency of the load to descend by its own weight which was not shown by the dynamometer. Mean draft shown by the dynamometer $212.5 + 122.8 = 335.3$ lb. resistance from friction, and $\frac{83030}{335.3} = 247.6$; or draft from friction $\frac{10}{2476}$ths of the load. Hence 9.04 lb. required to draw one ton of 2,240 lb.

5. Experiment made November 2, with the Lion, without the sparker, from the depot in Boston to Framingham.

LOAD OR TRAIN.

Tender as before.	
12 cars loaded with iron rails	Weight, 103,380 lb.
3 cars loaded with stones and iron	32,256
1 car loaded with apparatus and 2 persons	4,670
	Whole weight, 141,306 lb.

OUT.			RETURN.			Remarks.
	Time.	Mean Draft.		Time.	Mean Draft.	
	h. m. s.	lb.		h. m. s.	lb.	
To 1 mile post	5 30	978	To 20 mile post	2 45	956	Wind light from the northeast.
" 2 "	2 30	891	" 19 "	3 15	517	
" 3 "	2 55	675	" 18 "	2 55	337	
" 4 "	2 50	798	" 17 "	3 35	1122	
" 5 "	2 50	562	" 16 "	5 15	999	
" 6 "	3 35	891	" 15 "	3 0	90	
" 7 "	4 25	886	" 14 "	3 25	153	
" 8 "	4 5	562	" 13 "	3 0	697	
" 9 "	5 30	648	" 12 "	4 0	52	
" 10 "	5 10	729	" 11 "	3 35	0	
" 11 "	4 40	911	" 10 "	3 10	96	
" 12 "	13 0	1172	" 9 "	3 15	416	
" 13 "	7 30	1118	" 8 "	4 0	582	
" 14 "	3 20	675	" 7 "	2 40	756	
" 15 "	2 55	810	" 6 "	3 35	124	
" 16 "	4 15	1023	" 5 "	3 40	286	
" 17 "	4 35	450	" 4 "	2 40	621	
" 18 "	3 50	56	" 3 "	3 5	484	
" 19 "	3 25	655	" 2 "	3 15	434	
" 20 "	3 35	798	" 1 "	2 45	535	
To Depot at Framingham	2 15	240	To Depot in Boston	3 50	96	
	92 40	15,443		70 40	9383	
Time	1 32 40	7,354	Time	1 10 40	4468	

Wood used, being pine of ordinary quality. Out, 82.91 cubic feet. Return, 33 cubic feet.

Water used. Out, 58.84 cubic feet. Return, 59.5 cubic feet.

Wood used to evaporate one cubic foot of water. Out, 1.41 cubic feet. Return, 0.84 cubic feet.

Following the previous method of finding the resistance from friction, the load being 141,306 lb., we have: —

Out. $\frac{141306}{676} = 209$ lb. of the resistance shown by the dynamometer from elevating the load. Mean draft, $735.4 - 209 = 526.4$ lb. resistance from friction, and $\frac{141306}{526.4} = 268$, or draft from friction $\frac{1}{268}$th part of the load. Hence, 8.36 lb. required to draw one ton of 2,240 lb.

Return. $\frac{141306}{676} = 209$ lb., the tendency of the load to descend not shown by the dynamometer. Mean draft as shown by dynamometer $446.8 + 209 = 655.8$ lb. resistance from friction, and $\frac{141306}{655.8} = \frac{1}{215.5} = \frac{10}{2155}$ or draft from friction when reduced to level $\frac{10}{2155}$ths of load. Hence 10.39 lb. required to draw 1 ton of 2,240 lb.

6. Experiment made November 14, with the Lion, with the sparker on the engine, from the depot in Boston to Framingham.

LOAD OR TRAIN.

Tender as before.		
12 cars loaded with rails	Weight,	103,380 lb.
3 cars loaded with stones and iron		33,256
1 car loaded with apparatus and 2 persons		4.670
	Whole weight,	141,306 lb.

OUT.			RETURN.			Remarks.
	Time.	Mean Draft.		Time.	Mean Draft.	
	h. m. s.	lb.		h. m. s.	lb.	
To 1 mile post	4 55	995	To 20 mile post	2 50	945	
" 2 "	3 0	733	" 19 "	3 10	528	Wind light from the north.
" 3 "	3 10	484	" 18 "	3 15	225	
" 4 "	4 25	675	" 17 "	4 15	990	
" 5 "	3 40	531	" 16 "	5 10	950	
" 6 "	4 10	772	" 15 "	3 5	67	
" 7 "	4 40	886	" 14 "	2 50	135	
" 8 "	3 45	645	" 13 "	3 15	472	
" 9 "	3 30	337	" 12 "	3 40	87	
" 10 "	6 10	742	" 11 "	2 57	54	
" 11 "	3 30	860	" 10 "	3 18	144	
" 12 "	12 15	1219	" 9 "	3 25	326	
" 13 "	4 55	1114	" 8 "	3 35	398	
" 14 "	3 0	641	" 7 "	3 30	636	
" 15 "	3 5	723	" 6 "	4 0	324	
" 16 "	4 10	962	" 5 "	3 50	213	
" 17 "	4 30	506	" 4 "	3 0	499	
" 18 "	3 25	34	" 3 "	3 25	282	
" 19 "	3 30	731	" 2 "	3 25	355	
" 20 "	3 25	702	" 1 "	2 55	400	
To Depot in Framingham	2 35	90	To Depot in Boston	3 55	97	
	89 45	14,382		72 45	8,127	
Time	1 29 45	685	Time	1 12 45	387	

Wood used, being pine of ordinary quality. Out, 67 cubic feet. Return, 44 cubic feet.

Water used. Out, 53.42 cubic feet. Return, 43.35 cubic feet.

Wood used to evaporate one foot of water. Out, 1.25 cubic feet. Return, 1.01 cubic feet.

Following the former method of finding the resistance from friction, the load being 141,306 lb., we have: —

Out. $\frac{141306}{676} = 209$ lb. of resistance shown by dynamometer from elevating the load. Mean draft, $685 - 209 = 476$, resistance as reduced for a level, and $\frac{141306}{476} = 296.8$; or draft when reduced to a level $\frac{10}{2968}$ths part of the load. Hence, 7.55 lb. required to draw one ton of 2,240 lb.

Return. $\frac{141306}{676} = 209$ lb., the tendency of the load to descend not shown by the dynamometer. Mean draft shown by dynamometer $387 + 209 = 596$ lb. resistance from friction, and $\frac{141306}{596} = 237$; or draft when reduced for a level $\frac{1}{237}$th part of load. Hence 9.45 lb. required to draw one ton of 2,240 lb.

NOTE. — Calculating in the ordinary mode from the mean traction during the passage up the road, we find the engine a 25 horse-power. From the experiments up and down, it appears that the load 63 tons would be drawn over a level 20½ miles with 60 cubic feet of wood. Cost at $6 a cord, $2.81. Then one ton drawn over a level one mile at an expense for wood of 2¼th mills.

I. To obtain from the experiments herein related the effect of the sparker, I take from them the following facts: —

1st. Wood and water required in going to and returning from Framingham, 41 miles.

	Sparker on.		Sparker off.	
	Wood.	Water.	Wood.	Water.
	Mercury.			
Out,	83 cubic feet.	53.4 cubic feet.	67.0 cubic feet.	52.6 cubic feet.
Return,	60 " "	42.5 " "	48.7 " "	40.6 " "
	143 " "	95.9 " "	115.7 " "	93.2 " "
	Meteor.			
Out,	61 cubic feet.	37.50 cubic feet.	42.0 cubic feet.	39.42 cubic feet.
Return,	40 " "	31.55 " "	20.5 " "	20.13 " "
	101 " "	69.05 " "	62.5 " "	59.55 " "
	Lion.			
Out,	67 cubic feet.	53.42 cubic feet.	82.91 cubic feet.	58.84 cubic feet.
Return,	44 " "	43.35 " "	33 " "	39.50 " "
	111 " "	96.77 " "	115.91 " "	98.34 " "
Total	355 cubic feet.	261.72 cubic feet.	294.11 cubic feet.	251.09 cubic feet.

2d. Time required in going to and returning from Framingham, 41 miles, with the mean draft as shown by the dynamometer.

	Sparker on.				Sparker off.		
	m.	s.			m.	s.	
Mercury.							
	91	15	out.		75	55	out.
	69	45	return.		64	15	return.
Time	161	50	Mean draft, 414.3 lb.	Time	139	10	Mean draft, 467 lb.
Meteor.							
	106	45	out.		89	40	out.
	83	25	return.		63	0	return.
Time	190	10	Mean draft, 232.4 lb.	Time	152	40	Mean draft, 310.4 lb.
Lion.							
	89	45	out.		92	40	out.
	72	45	return.		70	40	return.
Time	162	30	Mean draft, 536 lb.	Time	163	20	Mean draft, 591.1 lb.

Time required in running the 123 miles with the sparker on, and the same distance without the sparker, with the mean draft in both cases.

Sparker on.		Sparker off.	
	m. s.		m. s.
Time	513 40	Time	455 10
Mean draft	427.6 lb.	Mean draft	466.2 lb.

By the above it appears that, although the loads in the parallel experiments with and without the sparker were almost identical, the draft or traction when the sparker was not used was nine per cent greater than when it was used. I attribute this difference to some slight and accidental difference in the state of the road, or to the condition of the oil upon the journals (or gudgeons), or to both these combined. Adding to this nine per cent for the wood and water used when the sparker was on the engine, we find required to produce equal effects, taking the mean of the parallel experiments, about thirty per cent more wood and thirteen per cent more water when the sparker is on than when it is off. As the draft of air through the fire and chimney is less rapid when the sparker is upon the engine, we should expect to find the combustion less perfect, and consequently a greater quantity of wood required to produce a given effect, measured either by the evaporation or the power of the engine. We should not only expect a diminished effect from these causes, but likewise, as the time in passing over the road was greater when the sparker was upon the engine, there must have been a greater loss of heat from the radiating and conducting surfaces exposed to the atmosphere. The experiments, therefore, in this case accord with the conclusion which we should form *a priori.* This, however, does not apply to the water, and we should expect to find that in this, as in other cases, the power would bear a close relation with the water expended. It will be observed, however, that there is a departure from this relation in the water used in all the experiments compared with the power as measured by the dynamometer, as the engine went up or down the road, and that from ten to forty-five per cent more water was used in proportion to the draft in the descending than in the ascending journeys. I cannot believe that any mistake was made in the measure of the water, and I know of no circumstance to which to attribute the difference but the greater velocity of the pistons in descending than in ascending the road, and to the steam being worked at a much less elastic force. These would both diminish the power from a given quantity of water formed into steam, perhaps in a degree sufficient to account for the apparent discrepancy. Neither of these circumstances is to be found, however, when we compare the passages, both up and down the road, with the sparker, against the same passages made without the sparker, and yet we have found that more water was required under the former than under the latter condition. The quantity of water, however, is of no importance in itself, and I have only stated it here for the purpose of bringing everything observed in the experiments into notice. I shall leave it with stating that the engineers who manage the engines on the Worcester road have an opinion that the resistance produced by the sparker to the free passage of the steam from the chimney after it has produced the stroke adds in some degree to the load of the atmosphere against which the piston is moved. This resistance must necessarily be very small, and it may well be doubted whether it be sufficient to be appreciated.

In comparing the velocities with and without the sparker, we find, if we add the nine per cent as in the former comparisons, that the time required for equal effects was about twenty-three per cent more when the sparker was on than when the engine was used without it.

The conclusion then is irresistible, that, under every relation of speed and economy, the sparker is in some degree disadvantageous. At the same time, it cannot be doubted that the comfort of the passengers, and to some extent their security and that of their property, are increased by it.*

II. *Next for the effect produced by engines of different sizes.*—We find that in transporting one ton of 2,240 lbs. to and from Framingham, which may be taken as equivalent to a level railroad of 41 miles in extent, the consumption of wood and water was as follows.†

		Wood.	Water.
Mercury,	10 inch cylinders	2.69 cubic feet.	2.17 cubic feet.
Meteor,	9 " "	1.68 " "	1.60 " "
Lion,	11 " "	1.33 " "	1.56 " "

From this it appears that, contrary to the common opinion, the greatest effect was produced from a given quantity of fuel when used in the smallest engine. I entertain no doubt, however, that this was from the better condition and adjustment of that engine, which, though not apparent to common observation, for all the engines appeared in equally good order, yet really existed, and that the largest engines when equal in construction and in equal order will produce somewhat greater effects than the smaller. Moreover, the expense for the engineer and other persons required for the management of the engine

---

* Some form of sparker is used at the present time, on all locomotives. — W.

† I take only the trials where the sparker was not used, as the locomotive engine is at present most commonly used in that form.

and train is the same, whether the engine be large or small; therefore the whole cost of transportation must be much enhanced by the employment of small rather than large engines.*

III. *The comparative power of the same engine using steam of a given elastic force when running at different velocities.* — It is well known that the power of any steam-engine driven by steam of a given elastic force, measured by the pressure exerted by the piston rod, is greater in some inverse proportion to the velocity of the piston. Thus, for example, a locomotive engine running without any resisting train upon a level railway will acquire such velocity that the elastic force of the steam and the resistance opposed to it in the several pipes and narrow passages through which it must pass is such that in following the pistons a very small force is displayed upon them. When, however, we add a resisting train to an engine under the above condition, we reduce the speed, and consequently reduce the resistance to the passage of the steam itself, and it is only when we increase the resisting train so that the velocity becomes barely sensible that the full effect of the elastic force of the steam is communicated to the piston. We may determine some of the relations of the power of an engine under different velocities from data furnished in the preceding accounts of my experiments.

It appears that the Lion, when ascending the inclination between the tenth and thirteenth mile drawing a load of 141,806 lb., exerted during one mile a mean force of 1,219 lb., and moved at the rate of 4 miles an hour. During a portion of the time the motion was something less than 2¼ miles an hour, and the drag was then 1,350 lb. upon the dynamometer.

The driving wheels of this engine are five feet in diameter, the strokes in the cylinder sixteen inches; therefore the motion of the engine over the rails is to that of the piston as 32 to 188.5, or 1 to 5.9 nearly. Hence the whole force upon the pistons must have been 7,192 lb. Here are two cylinders, containing together an area of 190 square inches. The force then which was communicated from the piston to the dynamometer alone must have required a constant pressure upon the pistons of 37.8 lb. per inch. In addition to the above pressure, which was measured by the dynamometer, there was the power required to move the engine itself and its tender, being fifteen tons, which was not measured by the dynamometer. Taking into the account the large journals (or gudgeons) of the engine and tender, we may take this to have required 400 lb., which would give 12.4 lb. per inch upon the pistons. The steam during this time was blowing freely from the safety valve loaded with 60 lb. per inch, and giving probably a pressure in the boiler of 56 lb. to the inch. The 5.8 lb. difference between 50.2 lb., required upon the pistons, and 56 lb., the pressure in the boiler, may fairly be assigned to overcoming the resistance of passing the pipes, the friction of the pistons, slides, and other working parts of the engine, and the resistance of the forcing pumps.

From the foregoing statements we may conclude that a locomotive engine using steam of 60 lb. per inch, as shown by the safety valve of common construction, will produce a useful effect upon a train of 38 lb. upon each square inch of its pistons when the velocity upon the road is not greater than four miles an hour.

To find the effect of the steam upon the engine at higher velocities requires more extensive experiments made upon a road containing longer levels, or planes of equal inclination, than those of the Worcester road. I may, however, make one comparison, which I consider as indicating a solution of this question worthy of some reliance. The road from the first to the fifth mile-post, containing but one ascending plane, was passed over by the Lion and train, steam being 60 lb. as measured by the safety valve, in $14^{m.}$ $15^{s.}$, or at the rate of 17 miles an hour, nearly; the mean draft upon the dynamometer being 606 lb. This required, following the former mode of computation, an effect upon the pistons to be communicated to the train of 18.7 lb. to the inch. We have, then, when the steam is 60 lb. in the boiler, 38 lb. useful effect upon the pistons, the velocity being 4 miles an hour, and 18 lb. when the velocity is 17 miles an hour. It may be observed that these forces are to each other very nearly in the inverse proportion of the square roots of the velocities. The experiments, however, were much too limited to warrant the inference of a general law from them.

---

* Mr. Treadwell's view has been fully confirmed by subsequent observation. — W.

IV. *Curves.* — One of the questions of considerable importance in the economy of railroads which has yet remained undetermined, is presented in the resistance produced by passing the loads over the curves in the road, made in horizontal planes, as compared with moving in straight lines upon the same planes. The Worcester road contains no level curve of sufficient length to yield any experiments for solving this question. I often made direct observations, however, upon the dynamometer, as the trains passed the short level curves, and I was seldom able to perceive any sensible increase of the draft over that required for the same train upon the straight parts of the road.

A single experiment was tried on a part of the road three miles in length, and made up of a series of curves. To find the resistance produced by the curve alone we may take the resistance due to the common friction on the level and straight railway as shown by these experiments, and the resistance due to elevating the load as shown by calculation, and the sum, whatever it may be, which is required to make them equal to the actual and observed resistance may be taken as the resistance due to the curves. The results from this experiment failed to show any essential resistance from the curves by the method followed, and yet it is evident that the cars pass more freely upon the straight than upon the curved parts of a railway. . . . I think that we may conclude that the resistance from a curve of 2,000 ft. radius is not greater than $\frac{1}{3640}$th part of the load, or an elevation of two feet in a mile. With curves of a smaller radius the resistance is increased probably in a much more rapid proportion than that of the reduction of the radius.

A more important objection to curves than that of their increasing the resistance, however, is found in this: that as they generally pass round hills or through deep cuts, it is impossible for the engineer when upon them to see whether the road is clear and passable for many rods before him. Hence he must either run very slowly, or be in constant danger of accident. This danger is so great that it is always advisable to obtain for all railways straight lines, if possible, even if at the disadvantage of having them of such ascents as shall yield resistances many times greater than would be given by the curves for which they have been substituted.*

V. *Experiments to determine the Resistance of Cars mounted upon Gudgeons of different Sizes, when running upon Railroads.*

Saturday, October 29th, run with the engine Meteor twice to Newton Corner, drawing each time two cars, as follows: —

Experiment No. 1.	1 car carrying apparatus and two persons; gudgeons $1\frac{7}{8}$ inches in diameter, weight,	4,670 lb.
	1 car loaded with iron; gudgeons 3 inches in diameter, weight	11,150
		15,820 lb.
Experiment No. 2.	1 car carrying apparatus as in experiment No. 1 (the same car and load was used for the apparatus in all the experiments), weight	4,670 lb.
	1 car loaded with stone and iron; gudgeons $1\frac{7}{8}$ inches in diameter, weight . . .	9,210
		13,880 lb.

The wheels of all the cars used are three feet in diameter. The weights named are those of the cars and their loads.

---

* The effect of curves contains many factors, — the relative height of the inner and outer rails, the form of the tread of the wheels, the length of the train independent of the load, and the velocity. It is still a subject of discussion with civil engineers. The practical objection to curves as regards safety is fully acknowledged, even when the road is worked with the aid of the telegraph. Mr. N. N. Forney, in his book on Locomotives, says (1886): "It may be stated that the most recent experiments have shown that the resistance of good American cars does not exceed 6 lb. per ton of 2,000 lb. at very slow speed on a straight and level track. With reference to the influence of speed on the resistance, it must be admitted that our knowledge is very inexact, and probably the law or laws which govern it is not well understood. Our knowledge of the resistance due to curves is also in a very unsatisfactory condition, but the most reliable information we have indicates that the resistance is equal to about half a pound per ton of 2,000 lb. per degree of curvature." Mr. Treadwell's experiments with a speed of 15 miles an hour, a curve of 2,000 feet radius (3°) treated by the methods now adopted, would give a resistance of 8.5 lb. to the ton of 2,240 lb., substantially the same as that obtained from recent experiments. — W.

EXPERIMENT No. 1.

Time.	m. s.	Mean Draft. lb.
To 1 mile post	2 50	196
" 2 "	2 31	123
" 3 "	2 34	105
" 4 "	2 27	135
" 5 "	2 30	80
" 6 "	3 8	122
To Newton Corner	1 20	75
	16 0	836
Mean draft of whole distance		119.4

EXPERIMENT No. 2.

Time.	m. s.	Mean Draft. lb.
To 1 mile post	2 40	185
" 2 "	2 40	106
" 3 "	2 30	72
" 4 "	2 17	97
" 5 "	2 38	52
" 6 "	2 45	84
To Newton Corner	1 5	45
	16 35	641
Mean draft of whole distance		91.6

These experiments were made during a strong west wind.

Tuesday, November 1st. Run through the above distance with the engine Lion drawing the cars as described in the foregoing experiments. Experiment No. 3 gives the account when the cars with large gudgeons was tried. Experiment No. 4 gives the account when the car with small gudgeons was tried.

EXPERIMENT No. 3.

Time.	m s.	Mean Draft. lb.
To 1 mile post	3 20	157
" 2 "	2 10	130
" 3 "	2 15	117
" 4 "	2 10	113
" 5 "	2 10	93
" 6 "	2 45	162
To Newton Corner	50	0
	15 40	772
Mean draft of whole distance		110.3

EXPERIMENT No. 4.

Time.	m. s.	Mean Draft. lb.
To 1 mile post	3 5	134
" 2 "	2 13	83
" 3 "	2 22	47
" 4 "	2 10	64
" 5 "	2 26	42
" 6 "	2 39	57
To Newton Corner	1 5	48
	16 0	475
Mean draft of whole distance		68

The car used in experiment No. 4 had immediately before this trial run thirteen miles upon the road, by which the gudgeons and boxes had become warm, and the oil and tallow used upon them softened. Considering this as affecting the experiment by reducing the resistance, I made a trial with the same car, on Friday, November 4th, taking the car and load after it had been at rest and the gudgeons and boxes were cold.

Experiment made Friday, November 4th, with the engine Jupiter drawing the car tried in Nos. 2 and 4, the gudgeons and boxes being cold.

EXPERIMENT No. 5.

Time.	m. s.	Mean Draft. lb.
To 1 mile post	2 42	155
" 2 "	2 18	90
" 3 "	2 30	60
" 4 "	2 32	66
" 5 "	2 30	54
" 6 "	3 18	55
To Newton Corner	50	60
	1640	540
Mean draft of whole distance		77.1

The rise to Newton Corner is 45 feet. Distance 6¼ miles = 33,000 feet, which is one foot in 733. Then we have the load carried in Nos. 1 and 3 — 15,820 lb. ÷ 733 = 21.6 lb. — as the resistance from elevating the load 45 feet in 33,000, and the load used in Nos. 2, 4, and 5 — 13,880 ÷ 733 = 18.9 lb. —

as the resistance from elevating this load 45 feet. We have likewise the mean draft of the load used in Nos. 1 and 3.

Nos. 1 and 3, $119.4 + 110.3 = 114.8$ lb., mean of both.

From this take 21.6 lb., being the quantity due to elevating the load, and we have 93.2 lb. for the resistance from all other sources. Then, if we reject experiment No. 4, as not made under the same circumstances with the others, we have the mean draft in

Nos. 2 and 5, $91.6 + 77.1 = 84.3$ lb., mean of both.

From this take 18.9 lb., being the quantity due to elevating the load, and we have 65.4 lb. for the resistance from all other sources. Then, if we divide the loads in both cases by the resistance from these sources we have results as follows:—

$$\frac{15820}{93.2} = 169.7, \qquad \text{and} \qquad \frac{13880}{65.4} = 212.2.$$

That is, in Nos. 1 and 3 the resistance reduced to a level railway was $\frac{10}{1697}$ths of the load. Or they give one ton of 2,240 lb. drawn by 13.2 lb., and in Nos. 2 and 5 the resistance reduced to a level was $\frac{10}{2122}$ds of the load, or one ton of 2,240 lb. drawn by 10.55 lb. In experiments Nos. 1 and 3, a part of the load, namely, that of apparatus car, was carried upon gudgeons of $1\frac{7}{8}$ inches diameter. Let us then, to ascertain if the resistance was in proportion to the diameters of the gudgeons of the cars on which it rested in each set of experiments, multiply the load carried by the diameters of the gudgeons. Thus:

Nos. 1 and 3, $4{,}670 \times 1\frac{7}{8} = 8{,}756$
" " $11{,}150 \times 3 = 33{,}450$
$42{,}206$
Nos. 2 and 5, $13{,}880 \times 1\frac{7}{8} = 26{,}025$

We have the proportion, $26{,}025 : 42{,}206 :: 65.4 : 101.8.$

But we have found that the resistances reduced for a level were as $65.4 : 93.2$. The resistance, therefore, does not follow the exact proportion of the size of the axles or the gudgeons, although it approaches somewhat near to that ratio. It must be evident, however, that a part of the resistance is produced between the wheels and the rails. Some force is destroyed by the motion of the rails in the chairs, and there is, moreover, some resistance from the passage of the load through the air. If we take the force of traction required to overcome all these resistances as equal to $\frac{1}{600}$th part of the load, we have for the friction of the gudgeons in

Nos. 1 and 3, the load $15{,}820 \div 600 = 26.3$
Nos. 2 and 5, the load $13{,}880 \div 600 = 23.1$

and the traction for a level in

Nos. 1 and 3, $93.2 - 26.3 = 66.9$
Nos. 2 and 5, $65.4 - 23.1 = 42.3$

That is, the resistance from friction, at the gudgeons alone, in Nos. 1 and 3 was 66.90 lb. and in Nos. 2 and 5 it was 42.3 lb. Then, taking the loads in both cases multiplied by the diameters of the gudgeons, we have the proportion $26{,}025 : 42{,}206 :: 42.3 : 68.9$, which accords very nearly with the experiments. It is said that the cars and wheels now used upon the Worcester road, if mounted upon larger gudgeons, will be strong enough to carry much larger loads than three tons, to which they are now limited. This raises the question whether, considering this greater weight of load in connection with the weight of the cars, it will not be good economy to use the large gudgeons carrying these greater loads? Let us examine this question.

Suppose a car alone to weigh 2,600 lb., and that we load it with 6,000 lb., the actual resistance will be found as follows, for gudgeons of $1\frac{7}{8}$-inch diameter: $2{,}600 + 6{,}000 = 8{,}600 \div 212.2 = 40.5$ lb. For carrying loads upon cars with 3-inch gudgeons, loaded with double the above weight, we have

$2{,}600 + 12{,}000 = 14{,}600 \div 156.6 = 93.2$ lb.,* or a traction of about $\frac{1}{6}$th more in transporting a given quantity under these circumstances upon cars with 3-inch gudgeons than is required for transporting the same quantity upon cars with $1\frac{7}{8}$ in. gudgeons. This calculation is founded upon the supposition of the transportation being upon a level railway. Let us take the case of ascending a plane of thirty feet in a mile, for in all cases upon the Worcester road the power of the engine must be sufficient to ascend such planes, and such engines will draw any loads upon the levels which they can carry over the ascents. Take, therefore, a car, gudgeons $1\frac{7}{8}$ in. diameter, weight 2,600, load 6,000 lb., and we have for the resistance upon the level, as has been before seen, a traction of 40.5 lb., and for elevating the load only on a thirty feet inclination $\frac{1}{176}$th part of the weight. Then $\frac{8600}{176} = 48.8$, and $48.8 + 40.5 = 89.3$ lb. traction up the plane. A load of 12,000 lb. upon a car weighing 2,600 lb., gudgeons 3 in. diameter, has been found to require upon a level a force of traction of 93.2 lb.; add to this $\frac{14600}{176} = 83$ lb. for elevating the load, and we have $83 + 93.2 = 176.2$ for the traction in this last instance. That is, we have in useful effect a transportation in the first case of 6,000 lb. by a traction of 89.3 lb., and from the last a transportation of 12,000 lb. by a traction of 176.2 lb. Or a double load moved up the inclined plane by a very little less than a double force.

Very respectfully yours,

DANIEL TREADWELL.

BOSTON, March 25, 1837.

III. — See page 409.

IMPROVEMENT IN MACHINERY FOR WELDING AND FORMING WROUGHT IRON CANNON.

Fig. 1 is a longitudinal section of such machinery shown in elevation. Fig. 2, a plan of the same machinery in section. Figs. 3 and 4 are cross sections made through parts which will be described.

A A A A represents the frame of a hydrostatic press; the upright pieces (Fig. 1) are heavy pieces of cast iron, and the horizontal pieces are bars of wrought iron. The top bars are supported by straps passing round deep pieces of timber.

B B, a large cast iron bed-plate having two rails projecting upwards, as shown at Fig. 3 and 4 in cross section, upon which the chair X, hereafter to be described, can be moved lengthwise. C C, cylinder of the press hooped with wrought iron; D, piston; seen in cross section at Fig. 3. The piston or ram has a cylindrical cavity running nearly through it. E E (Figs. 1 and 2), a cast iron guide-box bolted to the head of the cylinder to direct the forward and backward movements of the piston. F F, pipe leading from the pump of the press to the cylinder D. G G, system of weights and bent levers to draw back the piston when the water leaves the cylinder. H H, a cast iron spindle resting upon the cast iron chair, I I. A hole somewhat larger than the cannon to be formed runs through this spindle, and one end of the round bar of iron, or backing pin, K K, may be run through this hole. L L, a spindle similar to H H, bolted upon the end of the piston. The mandrel, a punch, M M, passes through this spindle. This mandrel is connected with the rack, N N, one end of which passes into the cavity of the piston, and can be moved backwards and forwards in that cavity by means of the crank and axle O O, and the pinion P. When the rack is passed out of the cavity of the piston, it passes into the hole made through the spindle L L, and carries the mandrel M M through and out of the spindle L L. This mandrel is somewhat conical, being about a quarter of an inch larger at the end next the rack than at the other end. R, R, R, R, are blocks of cast iron having a bottom and two sides projecting upwards so as to leave a rectangular cavity in which

---

* This 156.6 lb. is found as follows. Of the 15,820 lb. carried in Nos. 1 and 3, 4,670 upon the small gudgeons required a force of traction upon a level of $\frac{46700}{2122} = 22$ lb., and the remaining 11,150 required a force of traction of $93.2 - 22 = 71.2$ lb. Hence $\frac{111500}{712} = 156.6$. Or $\frac{10}{1566}$ths of the load.

the bar or backing pin K K lays along. Each block rests upon a chair, marked S S, etc., the under side of each chair being notched upon the projecting rails of the bed-plate B B, so that it can slide upon the rails to or from the cylinder. Upon the inside of the right-hand block, as seen in the drawing (Fig. 2), projections are seen, against which the short bar of iron *d* can be placed across against the back end of the backing pin K, and prevent it from passing backwards in operations to be described. The place of the spindle H H upon the bed-plate B B is always determined by the number and length of the blocks behind it. U (Fig. 1) and U (Fig. 2) are sets of cast iron placed upon the end of the spindle H H, and supported there by a ring which passes into the hole in the spindle H H, and into the body of the set. V V is a set similar to U, and is supported upon the end of the spindle L L by a ring in the same manner as U is supported on H. These sets are short cylinders of cast iron. Holes are made in them through which the mandrel M passes. The faces of the sets U (Fig. 2) and V (Figs. 1 and 2) are creased or furrowed, in the direction of rays from a centre, about a quarter of an inch apart, and leave between them sharp projections which form creases in the hot iron against which they are to be pressed. The face of the set U (Fig. 1) has a circular projection, which makes a circular depression in the hot iron against which it is pressed. A number of these sets are required, of different external diameters, to suit the rings to be made and the tapering form of the cannon. W W is the mould, being the hollow frustum of a cone, made of cast iron and hooped with strong wrought iron hoops. This mould rests upon a chair, X X, which is notched upon the projecting rails of the bed-plate which guide it in its motions backward and forward. The chair rests upon four small wheels, Y Y, running in boxes which are pressed downwards by the springs *e e* (Fig. 2 and 4), which are sufficiently stiff to bear the weight of the chair, the mould, and the cannon which is to be formed in the mould. The mould is secured upon the chair by the bars *f*, *f*, and the bolts *g*, *g* (Figs. 1 and 4), the lower ends of which are hooked under the frames *h*, *h*. *i*, *i*, *i* (Fig. 4) are staves of wrought iron running through the whole length of the mould. They are of different thicknesses according to the required diameter of the mould.

For heating the iron used in the manufacture of the gun, there is a reverberatory furnace with a hearth about four feet square, and two doors, one on each side, opening to the hearth, at one side of the press opposite the cylinder. A crane is placed in such position that a pair of tongs suspended from it will bear the cannon or any part of it from the furnace to the press. Two of the largest of the rings, the manufacture of which will be described, are then put into the furnace and heated to a welding heat; they are then placed near each other, end to end, and a large iron bar run through them both. The end of this bar is nearly as large as the hole in the rings. By another bar, passed through the other door of the furnace, the two rings are put gently together, so that they will adhere to each other. In this and in every other operation of putting the cannon together in the furnace, care must be taken that no sand or cinders be enclosed in the joint. . . . The bar inserted through the rings is about fifteen feet long. The rings, being made to adhere to each other, are next, when at a welding heat, removed from the furnace by suitable tongs suspended from the crane, and carried to the press and held between the sets U and V (Fig. 1), the mould having been carried back against the piston D, with the spindle L passing through its cavity. By turning the pinion P by means of the crank O, the mandrel M is then thrust through the inside of the heated rings. The tongs are then removed, and then, by means of the rack Z Z (Figs. 1 and 2), the pinion *a a*, and the arms *d*, *d*, to which the power of men is applied, the mould is drawn rapidly forward so as to enclose and cover the rings. (The mould may be moved by a falling weight.) The press is then put in motion, and, the set V approaching the set U, the rings are pressed between them and welded perfectly together. The mould at this time prevents the too great enlargement of the rings upon the outside, and causes the rings to take the form of the inside of the mould or the staves which line it, while the mandrel M prevents the closing of the hole through them. The water is then drawn from the press, and the piston, by means of its connection with the weight G, is drawn backward, carrying with it the spindle L and the set V. The backing pin K is then passed along through the spindle H H, until its end meets the end of the mandrel M. Blocks of iron are then placed between the other end of the backing pin and the iron bar *d*. The press is then put in motion, and the end of the mandrel M pressed against the backing pin K, while the rings are forced forward by the set V, and are driven from a larger to a

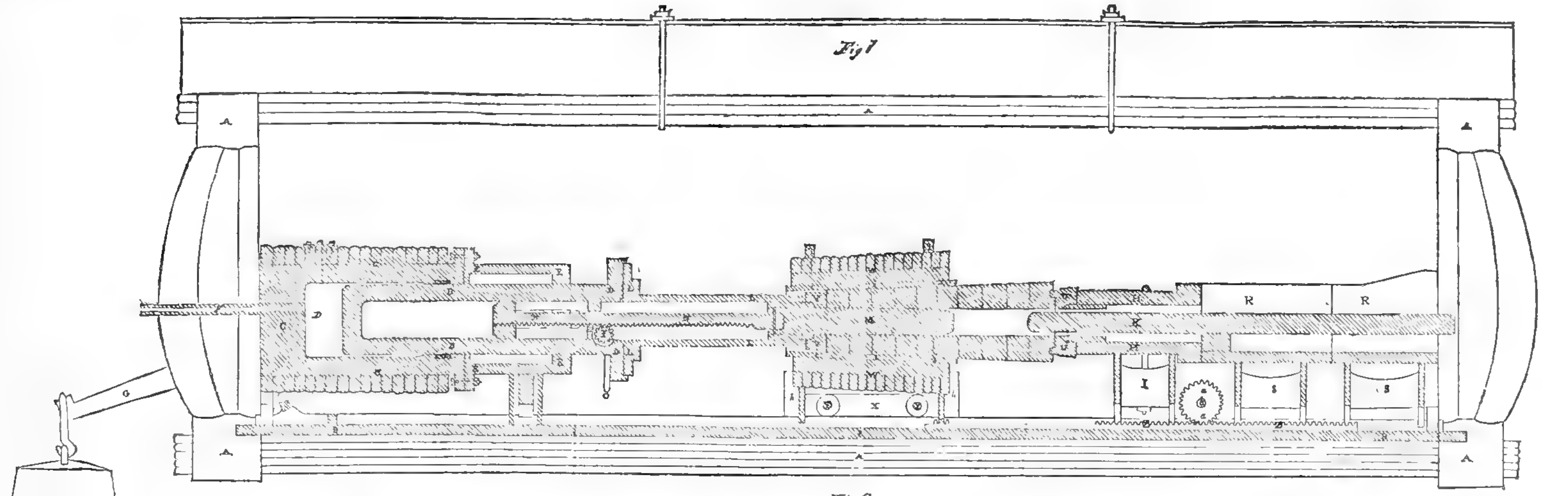


Fig 1

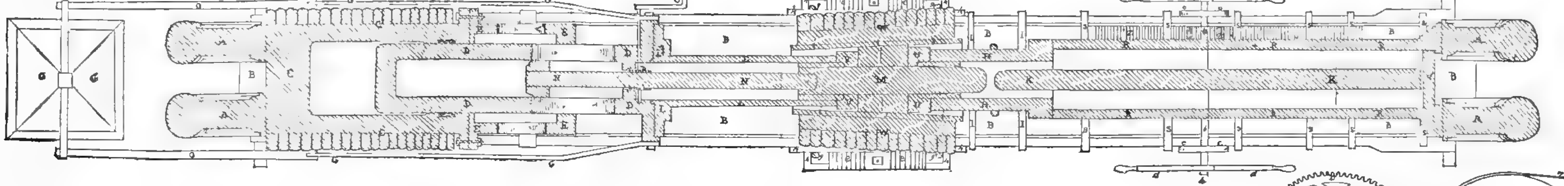


Fig 2.

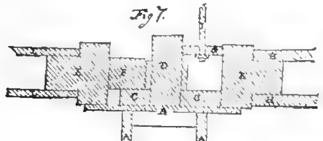


Fig 7.

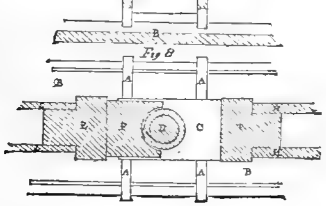


Fig 8

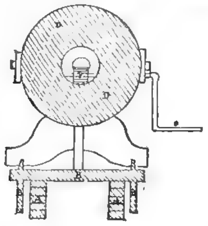


Fig 3.

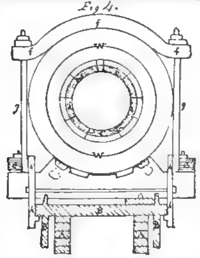


Fig 4.

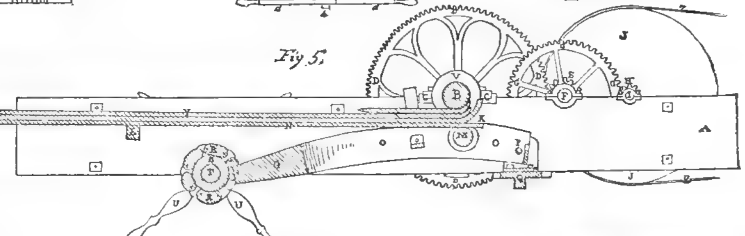


Fig 5.

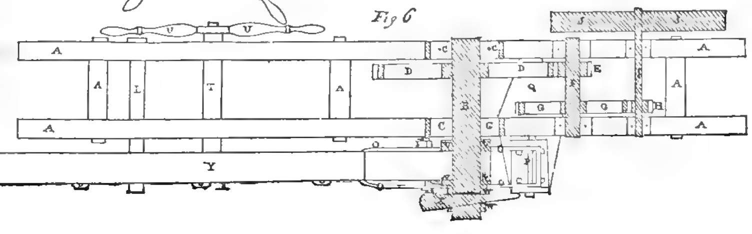


Fig 6

Drawing Correctly attached
[illegible] Forbes Ct. of Cl.

smaller part of the mandrel M and loosened so that the mandrel can be drawn out of them. The mould W W is then moved backward by the rack and pinion before described, and the ring or rings thrown from the mould. Fig. 2 shows the press in the act of uniting two rings as herein described. These double rings are again united end to end by a similar process, and so on till the cannon is formed. Solid cylinders may also be formed by first forming the rings and filling the hole with a solid iron bar, and heating both the rings and the bar to a welding heat; they can then be placed in the mould and welded together by the press.

Machinery for making and winding bars of iron for rings.—To form the rings for making a thirty-two-pounder. Take a bar of iron or steel, or a bar of iron and steel, about five and a half inches wide, twenty-three inches long, and one inch thick, and hammer each end into a wedge-like form for a length of about two inches; make one of these ends about six inches wide, and bend it through a length of about three inches into an arc of a circle of about three inches radius. The machinery for performing the further operations are represented in Figs. 5 and 6. Fig. 5 represents a longitudinal section, or elevation, of the machinery; Fig. 6, a plan of the same in section.

A A A is the frame, made of wood. B, a wrought iron shaft or spindle, turning in the boxes C, C. D D, a cog-wheel by which the spindle is turned. E E, a pinion upon the axle F, which gives motion to the wheel D D. G G, a cog-wheel upon the same axle F. H, a pinion upon the axle I I. J J, a pulley also upon the same axle I I. K K, an iron table resting upon the support L, and the roller M. N, a square bar of iron fixed to the under side of the table K (Fig. 5), and running in grooves in the support L and the roller M, when the table is moved in the direction of its length to prevent the lateral motion of the table. O O O, a large crotched bar or lever of iron, capable of turning upon the bolt P, which passes through the two open or crotched parts of the bar O O, and through projections which rise from the body of the support Q, which is a large piece of cast iron bolted firmly to the frame A A. The bar O O is connected at its other end, by the chain R R, with the barrel S, which barrel is fixed upon the axle T T and can be turned round by the arm U U. When the barrel S is turned and the chain wound up upon it (as shown in Fig. 5) the end of the bar or lever O O connected with it is raised, the other end of the same being kept in place by the bolt P. The roller M, which rests upon a bolt passing through its axis and through the two forks or arms of the lever O O, is likewise raised, and carries with it the table K, one end of which rests upon and is borne by it. V, V, are rings surrounding the spindle B (Fig. 6), the ring nearest the frame is fixed and immovable upon the spindle, while that nearest the end can be moved upon the same spindle in the direction of the length of the spindle; these rings are called griping rings. W W, a large ring, likewise upon the spindle B near its end. X X, a key or wedge which passes through a hole in the spindle B and the ring W; as this key or wedge is driven farther into, or through, the hole in the spindle, the outermost griping ring is carried nearer to the inner griping ring. Y Y is a bar of iron five and a half inches wide, resting upon the table K K. Z Z is the driving belt.

To use this winding machinery, the bar of iron, being heated, is placed upon the bar Y, resting on the table K; the curved end is placed directly under the spindle B. The arms U U are turned till, by raising the lever O, the table K, and the bar Y, the end of the heated bar is pressed firmly against the spindle B, as shown in Fig. 5. The key X is driven through the ring W and the spindle B; by this the bar is griped, and, the driving pulley J being put in motion, the bar and the table are moved along and the bar wound into a ring around that part of the spindle B that lies between the griping rings. The table and the lever O are then allowed to fall, the key X is driven out, and the outer griping ring taken off, and the bar, now formed into a circle, removed.

The bar thus formed is next to be welded at its ends. The machinery and tools for this purpose are represented in Figs. 7 and 8. Fig. 7 is a vertical longitudinal section shown in elevation. Fig. 8 is a plan of the same shown in section. This machinery is used in connection with the press. B B represents a part of the bed of the press. L and H represent parts of the spindles L and H as seen in Figs. 1 and 2. A A is an iron table standing upon the projecting rails of the bed-plate. C C is a thick plate of cast iron having a hole through it near its centre, through which passes the lower end of the pin D, which is supported on the top of the table A. E, E, are two sets, being square blocks of cast iron with plane faces; a cylindrical projection is formed upon the back sides of the sets F and E. The projection of one of the sets passes into the hole in the spindle H, the projection of the other set passes into the hole in the spindle L, by which means the sets are supported by the respective spindles. F is a swage, or die, made of cast iron, the face of which forms about one third of a hollow cylinder, and is placed opposite the pin D. G is a plate of cast iron suspended by a chain from any fixed point above it, and connected with the handle I. The part of this plate which is opposite the pin D forms part of a hollow cylinder corresponding to the diameter of the pin D.

To use this machinery, the bar of iron, which has passed through the winding machinery, being heated in the furnace to a welding heat, is carried to the press upon which the machinery just described stands, and placed upon the pin D with the tapering or wedge-like ends, which now lap over each other, between the pin D and the swage or die F. The plate of cast iron G is then placed between the pin D and the set E, as is seen in Fig. 7. The press is then put in operation, by which the spindle L is moved towards the pin D, and with it moves the swage or die F. By this motion the overlapping ends of the circular bar are pressed together and firmly welded to each other.

With the same machinery rings already formed may be enclosed in larger rings, until any required thickness is obtained, and, after being heated to a welding heat, they can be firmly welded in the press, and united to other similar cylinders until the requisite length is obtained.

Patent enrolled 20th June, 1846.

IV. — See page 440.

FRENCH REPORT ON TREADWELL'S 32-POUNDER, MAY, 1848.

[Translation.]

By order of the Duc de Montpensier a commission was appointed, April 4, 1847, to test the cannon of wrought iron and steel made and presented to the Government by Mr. Daniel Treadwell, Professor of Mechanics in the United States. This commission was composed of five officers of artillery. The following is an abstract of the report.

A programme arranged by the committee of artillery indicated the nature, course, and manner of procedure in this proof, article by article, with all the necessary directions. To this the commission has scrupulously conformed.

The external examination of the gun showed no cracks nor fissures. The turning was accurate, leaving only slight annular traces of the process of manufacture. The trunnion rings were perfectly screwed and riveted on the gun.

Interior examination with a mirror showed that the piece was perfectly sound without any honeycomb, fissure, crack, scratch, or marks of the borer. The examination at L'Étoile, and all the other examinations during the proof, indicate only the slightest differences in diameter, which in view of the frequent variations in the play of the gauge should be attributed to its imperfection rather than to the boring of the gun.

The table annexed to this report gives by simple inspection all the facts and results of firing 800 rounds in five series. Two prominent observations are in evidence from the comparison of the circumstances of this firing with those of the examination at L'Étoile: —

1st. The good *conduite* of the metal, and its resistance to these 800 rounds, which is shown by the perfect condition of the whole bore.

2d. The remarkable accuracy of the fire of the gun. The number of bull's-eyes (*blancs*) hit in a series of fifty rounds led to the anticipation of great accuracy of firing, but it was necessary to be present at all the sessions to appreciate the extreme certainty to which it had been carried at each round. The pointing was made with less precision, and more rapidly, than in the series devoted to this particular object: nevertheless the mean number of these hits was much greater than that of the howitzer of the Schools. The accuracy of the firing was simply a consequence of the perfect condition in which the whole bore is constantly maintained. It is this result which has especially fixed the attention of the commission. The successive verifications after each 50 rounds (by placing the gun on end and filling it to the face with water and hermetically closing it with a greased plug) indicated no change of diameter. There was not the least lodgment of the ball, nor beating (*battement*); as to certain variations in diameter they were very slight, and, not being repeated in successive verifications, they are not to be regarded. With the mirror and a bright sun the piece was well examined; not the least traces could be seen of beating, scraping, or degradation, even at the bottom of the chamber.

One circumstance remains to be pointed out, and that is the inconvenience of the great recoil of the gun. We ought to expect it, especially in the firing of the last series with charges of 2 kilo. 700 and a ball of 30 (32 English) in a piece which is but fifty-seven times the weight of the projectile. But it exceeded our expectations. The arrangements made did not prevent it from often running off the platform. It was also observed that the gun drooped much in the chase at each fire (*saignait fortement du nez*).

To recapitulate. The gun has borne this first proof, not only without the accidents we might legitimately expect from what usually occurs with iron guns, but also without those we might fear from the two peculiarities of its construction, viz.: 1st, the bottom of the chamber formed by a pin screwed into the breech; 2d, the trunnions fixed to the gun by a hoop screwed on and riveted. The breech pin, after being slightly unscrewed at the 147th round, was again screwed up, and never moved again; the gases did not injure the bottom of the chamber (there was very little escape of gas from the 4th session of firing). The trunnion hoops are in precisely the same condition as at the commencement of the firing. One of the small rivets or splines which appeared to fasten it was only slightly started at the last session. We may say, then, that the gun has borne this proof well, and appears to be in a condition to bear others still more severe.

Mr. Treadwell's principal object is the solution of the problem of lightening the armament of vessels without diminishing their force, that is to say, without diminishing the calibre of the guns. For this purpose he has endeavored to unite with a very light gun excessive strength or tenacity and hardness of metal, which will admit of the prolonged use of large calibres and high charges. Besides, he proposes a powerful and simple means for stopping the recoil on ships. He may then have a happy application of his improvements in the manufacture of iron cannon. Besides, if we could always obtain an accuracy of fire as remarkable and valuable as that of the cannon now under proof, should we not have reason to anticipate great advantages for field artillery without too great inconveniences?

It should be assured further that we can protect these pieces from rust, which acts more, and more constantly, on iron and steel than on bronze. These objections removed, it may be but a question of cost between these guns and those of bronze. The author has not informed us as to this important point in the manufacture. In view of the results obtained in this first proof, so well calculated to stimulate curiosity as to the limit of resistance of iron and steel thus wrought and welded, the commission is unanimously of opinion that the gun now under trial should be submitted to further proof.

Signé, BRAIVE, LEFRANÇAISE, DE TRYON (*Cap$^{\text{ne}}$ Rapporteur*),
BRADY, LADRANGE.

Pour copie conforme, Le Chef de Escadron Président,
Signé, BRAIVE.

VINCENNES, 18 May, 1848.

TABLE SHOWING THE RESULTS OF FIRING.

	Number of Sessions.	Length of Sessions.	Range of Powder as shown by éprouvette.	Distance of Target.	Elevation of Breech Sight.	Bull's-eyes.	Accidents and Observations.
		h. m.	m	m.	mm.		
1st Series. 100 shots with charge of 1.5 kilos and naval 16 lb. shell, with sabot; cartridge 145 mm. diam.	2	3 40	242	390	0	8	No accident during the firing. Tested with water after this series, there was a leakage of only 4 cu. cm.
2d Series. 200 shots with charge of 2 kilos, with shell and sabot.	4	3 45	239	540	0	6	At the 47th shot of the first session of this series, the breech-plug was so far unscrewed that it could be turned by hand; it was screwed in with a lever, and did not again become loose. Leakage, 1 cu. cm.
3d Series. 100 shots with charge of 1 kilo and 30 lb. ball.	2	3 30	236	470	80	5	Leakage, 1 cu. cm.
4th Series. 200 shots with charge of 2 kilos, with 30 lb. ball.	4	3 45	239	550	25	9	Leakage, 1 cu. cm.
5th Series. 200 shots with charge of 2.7 kilos and 30 lb. ball.	4	3 40	240	760	40	8	At the 148th shot, the stock was broken near the end of the cheeks where the assembling bolt passes through. One of the small rivets which fastens the trunnion ring had moved out slightly at the last session, without, however, disturbing the trunnion ring.

The Revolution of 1848 was then in progress, and on the 26th of May, eight days after the date of this report, the perpetual exile of Louis Philippe and his family was decreed. The further proving of the gun was never resumed, and it now stands (or did within a few years) in the Museum of Artillery of the School of Vincennes. — W.

INDEX.

END OF VOL. XI.