The Father of the Father of American Mathematics

Steve Batterson

At the turn of the twentieth century, University of Chicago mathematician E. H. Moore supervised three doctoral students who went on to lead the United States to its standing as an international center for mathematical research. Moore's students Leonard Dickson, Oswald Veblen, and George D. Birkhoff were the first domestically cultivated Ph.D. recipients (other than their advisor) to attain distinction through their mathematics and their academic progeny. E. H. Moore's role in this chronology has earned him the appellation "father of American mathematics" [1].

The biography and achievements of Moore are well documented [2]. Less accessible is information on Hubert A. Newton, Moore's advisor at Yale University [3]. Newton received a B.A. from Yale in 1850 and became the institution's only professor of mathematics in 1855. Another five years later Yale began the first Ph.D. program in America. As Newton himself never earned a Ph.D., he may be regarded as both the root and the grandfather of American mathematics.

Some of Newton's accomplishments are known. When the National Academy of Sciences was incorporated in 1863, he was one of the initial 50 scholars invited for membership. Moreover, Newton was the confidant and sounding board for J. Willard Gibbs, the greatest American scientist of the nineteenth century. Most of Newton's own research involved the study of meteors and comets. In 1895 he became vice president of the American Mathematical Society.

Hubert Newton died in 1896. His associations with Moore, Gibbs, the first American mathematics Ph.D. program, and the National Academy of Sciences make Newton an intriguing figure in the history of American science. This article employs archival materials to flesh out Newton's development in the context of the meager intellectual

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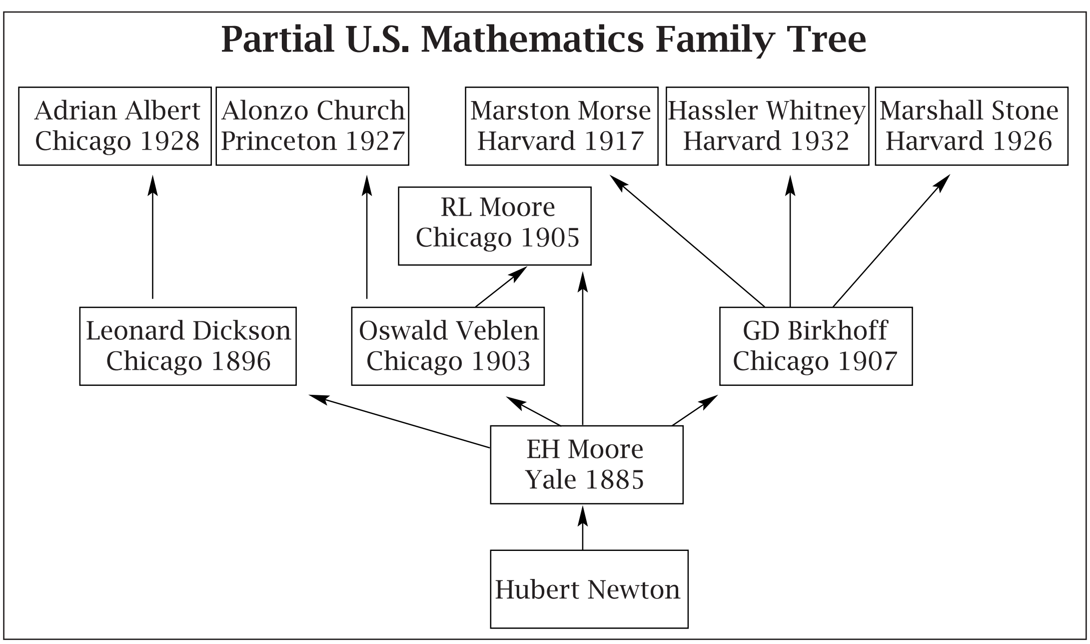


opportunities present in mid-nineteenth century United States.

I am grateful to Diane Kaplan and the Yale archives staff for kindly helping me to locate letters and records at the Sterling Memorial Library. I thank Ellen Neidle, Michele Benzi, and Albert Lewis for reading an early manuscript draft and offering their suggestions and encouragement. Conversations with David Borthwick clarified the celestial mechanics.

Becoming a Mathematician in the 1850s

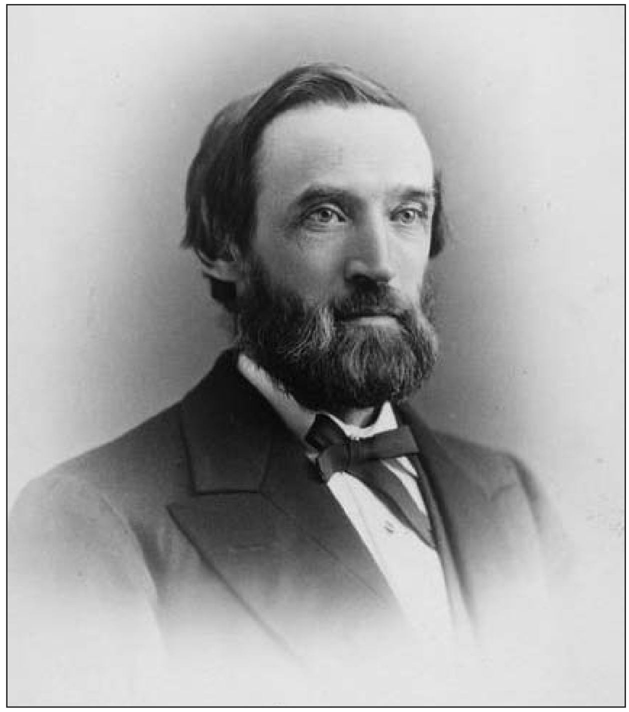
Hubert Anson Newton was born in the central New York town of Sherburne on March 19, 1830. His parents, William and Lois Butler Newton, were descended from families that migrated from England to the United States in the seventeenth century. William's father, Ashael Newton, fought in the Revolutionary War. When William's woolen factory was destroyed by fire for the second time, he became a contractor for the construction of the Erie Canal and other projects. Eventually the Newtons acquired a farm in Sherburne where Hubert was the ninth of eleven children.

In January 1847 Hubert followed his older brother Isaac to Yale. Living Yale alumni would not recognize the program then in place at their alma mater. Entering class enrollments numbered about 100 [4]. Attrition was high. Students were required to begin their day in the chapel at 6:30 for prayers. Recitation classes immediately followed the worship. The undergraduate college faculty consisted of just the president, seven professors, and a similar number of recent graduates who held the title of tutor. The curriculum was heavy in Latin and Greek with emphasis on rote learning.

All students took the same sequence of courses through the middle of their junior year. The offerings in mathematics were at a low level and had remained largely unchanged over the prior quarter century. Topics included algebra, Euclid, trigonometry, navigation, conic sections, spherical geometry, and mechanics. Calculus was among the options available to students for their first elective opportunity which arose at the end of the junior year. Most students selected a modern language instead.

Hubert Newton was a strong, but not exceptional student. Despite joining his classmates in the middle of their first year, Newton shared the freshman mathematics problem-solving prize. In his sophomore year Newton was the outright winner. No further prizes were awarded, perhaps because study of the subject was essentially complete.

Most Yale students were destined for legal or theological careers. Between the importance of honing oratorical skills and the absence of athletic and other campus diversions, debate societies flourished. Well into the third year of study came

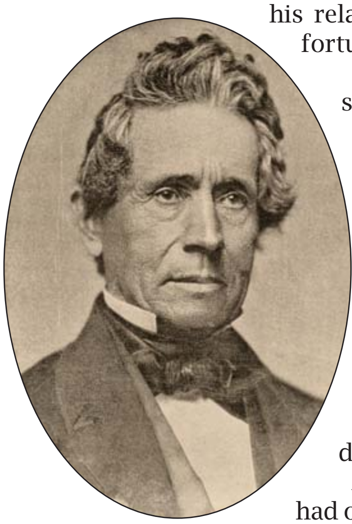


Hubert Newton.

the Junior Exhibition when the better students were selected to deliver orations and dissertations. Although Newton was a dedicated member of a debate society, he was not a scintillating speaker. One contemporary account mentions "a certain hesitation of speech and slowness of utterance" [4, page 397]. Nevertheless, Newton delivered an oration entitled "India" at the Exhibition. The text of his presentation is available in the Yale archives. To a modern reader Newton's well written narrative reeks of ethnocentrism and condescension: "there are indications that show a bright and glorious day to be near. The time when the Hindoos shall be freed from idolatry and become a Christian nation cannot be far distant" [5].

For Newton and the Class of 1850, their senior year took place with Zachary Taylor as United States president, California seeking to become the 31st state, and talk of southern secession in the air. The complex struggle over slavery was focused on the prospect of California tipping the delicate Congressional balance between free and slave states. Such current issues drove the topics for the debate societies. One week Newton assiduously prepared his position on the political compromise proposed by Henry Clay. The next week he readied an argument over whether the dissolution of the Union would be more injurious to the North or the South.

In a letter to a cousin on March 23, 1850, Newton discussed college activities, family news, and his future plans [6]. Two other cousins were among the masses drawn to California by the recent gold strike. One was in the "diggins" and the other was in Panama making the overland trip between the major boat voyages. Newton was skeptical of his relatives "realizing a very enormous fortune."



Denison Olmsted.

MADID #10594: Images of Yale individuals, ca. 1750–1976 (RU 684). Manuscripts and Archives, Yale University Library.

The debate preparations and his studies had worn Newton out. He was looking forward to graduation on August 15, expecting to stand about fifteenth in his class. The Yale calendar provided a vacation for seniors in July and August, except for those preparing addresses at commencement. With none of his friends planning to attend the ceremony, Newton was inclined to select leisure over an oratory opportunity on the podium.

As for his future plans, Newton had only ruled out joining the gold rush. He wrote to his cousin: "What I shall do after graduation I do not know. I may prepare to teach. I may study theology—perhaps shall study engineering. I hardly think I shall be a lawyer though I may." Notably absent, from today's point of view, is any consideration of obtaining a Ph.D. The explanation is simple. In 1850 no American university offered a doctoral degree. Yale, however, had recently taken a step in the direction of graduate education.

Yale consisted of its undergraduate college, divinity, law, and medical schools [7]. For many years some Yale graduates had remained on campus to continue, informally, their studies of Greek and other college subjects. Meanwhile interest was increasing in applications of sciences such as chemistry that were largely outside the traditional undergraduate curriculum. In 1847 Yale created a Department of Philosophy and the Arts to provide courses for both constituencies. The staff consisted of two new scientists together with professors already on the university faculty.

Although the Department of Philosophy and the Arts would evolve into a graduate school, no degrees were initially offered. The Master of Arts, authorized in the founding of the college in 1701, remained under the control of the undergraduate division. To obtain an M.A. a Yale student merely needed to wait three years after his B.A., pay five dollars, and, "in the interval, have sustained a good moral character" [8, 1856–57].

In its first year the Department of Philosophy and the Arts advertised calculus and analytical mechanics among its offerings. These courses were to be taught by Anthony Stanley. Stanley had become Yale's professor of mathematics in 1836 when Denison Olmsted's responsibilities changed from mathematics and natural philosophy to natural philosophy and astronomy. The academic sessions of 1850–51 were an especially bad time for Newton or for anyone to study mathematics at Yale. Stanley, still the only mathematics professor, was debilitated with tuberculosis. Over the year he would travel the world seeking a climate to facilitate his recovery [9].

After his graduation Newton returned home to Sherburne. Having decided to pursue mathematics further, he sought advice from Olmsted over how to proceed. Only Newton's November 1, 1850, reply survives of their correspondence. That Olmsted raised the possibility of study at Yale, or elsewhere, may be inferred from the context of Newton's words:

> I have pretty much concluded to pursue my studies at home this winter. I ought to look over a part of the mathematical studies of the College course. There are also some books which I think I can read with nearly the same advantage here as elsewhere. These are elementary mathematical books which I have not studied. I am now reading Analytical Geometry. These books I ought to understand to receive the most benefit from a teacher. Such reading would of itself be too dry and for a change I shall read books upon the Natural Sciences. Afterwards I expect to avail myself of the direction of a teacher…If I can have a good offer to teach I may yet accept it. But unless it was a good one I shall refuse [10].

It is notable that Newton recognized the importance of further mathematical training. He continued his reading at home, returning to New Haven in May 1851. By this time Stanley was on his way back from Egypt, but there was little hope that he could resume his duties. Quiet discussion was under way concerning the contingency of a vacancy in the mathematics chair. Olmsted had in mind James Hadley [9, page 290]. Hadley was a brilliant young Greek professor whose wide ranging expertise included mathematics and Sanskrit. These circumstances led to a meeting between Newton and Hadley that Hadley described in his journal:

> Friday, May 9…Newton, class of '50, has come to New Haven to study mathematics—with *me*, if he can. Should like to hear him, but believe it is impossible. My new textbook in history, my Greek optional, my labors in two biennial examinations and in that for the Woolsey scholarship, and besides all, the claims of a courtship nearing its close will leave me little time for a study so arduous.

> Saturday, May 10…more of the time talking with Newton, whom I had seen at 9. He will study by himself, French first and afterwards mathematics. Advised him to procure Moigno's *Calculus* [9, page 214, 215].

In the mid-nineteenth century the best advanced mathematical texts originated in Paris. For an American student a reading knowledge of French was essential. Hadley's Friday entry indicates a desire to take Newton on as a student. Courtship may have been the decisive obstruction. Hadley had recently become engaged. He and his fiancée had just begun seeing each other every day. The injection of Hadley into the story demonstrates the dearth of mathematical expertise in America. Yale was one of the best universities in the United States. Yet their second authority on mathematics was a 30-year-old full time Greek professor.

Hadley recorded one further meeting with Newton. It occurred later in the summer of 1851. The entry mentions that Newton was studying a book by the French mathematician Jean-Marie Duhamel. In the fall Newton returned to Sherburne. It is unclear how he was supporting himself. Perhaps Newton relied on his family or worked on their farm. In the second year after graduation he followed the same routine of study as in his first, remaining at home until May and then going to Yale.

While Newton was in Sherburne, Stanley aborted an attempt to return to the classroom. The tuberculosis was headed into a terminal stage. Hadley moved into the breach to handle calculus in the summer of 1852. By this time the college catalogue lists Newton as a student in the Department of Philosophy and the Arts. Although there is no record, it is likely that Newton took calculus from Hadley in 1852.

The situation in mathematics at Yale was untenable. Stanley was unable to teach. Hadley, whose real love was Greek, had a full plate of other responsibilities. Yale needed another teacher to cover the mathematics instruction. Tutors were always recruited from the best recent graduates. Newton's mathematics prizes and two years of subsequent study gave him a solid resumé, even if he were not a valedictorian or salutatorian. In July 1852 Newton accepted a tutorship. The annual salary was \$550 (professors received \$1,300).

Tutors held temporary positions that normally lasted a few years. Among the tutors there was a seniority system under which the newest hires taught the courses left over after all others made their selections. Thus a new tutor with a specialty in mathematics might be stuck with conducting Latin recitations. Whether through luck or a special concession to the needs of the college, Newton got mathematics when he assumed his duties in January 1853. Moreover, at age 22, he immediately found himself in charge of the entire mathematics program at Yale.

Newton had taken an important step toward an academic career. Stanley, Olmsted, and Hadley each had apprenticed as tutors at Yale prior to obtaining their professorships. However, with vacancies in a particular chair arising once a generation or so, only an exceptional tutor with fortunate timing had any realistic expectation of promotion. Many tutors went on to careers outside the academy. Some obtained positions at other colleges. Olmsted taught at the University of North Carolina for eight years before being called back to Yale.

Anthony Stanley died in the spring of 1853. For a replacement, Yale would want the leading mathematician from their alumni. On this basis Newton's few months of experience as tutor paled in comparison to the credentials of William Chauvenet and Theodore Strong from the classes of 1840 and 1812 respectively. Chauvenet had been instrumental in the recent founding of the United States Naval Academy where he was the professor of mathematics and astronomy. Moreover, Chauvenet had written a highly acclaimed textbook on trigonometry. Strong was a mathematics professor at Rutgers. He had published research, but was nearing the age of 63.

The Yale mathematics chair was offered to Chauvenet who decided to remain at the Naval Academy [11]. In his declination letter Chauvenet explained that the question was "so nicely balanced that it required but little to turn it either way." He went on to leave the door open by stating "that some of these [reasons] which have weight with me at the present are of a temporary character." The position would remain unfilled as Newton soldiered on with the responsibilities of a professor, the standing of a tutor, and an opportunity to impress.

Today, a young mathematician is advised that research, publication, and networking are the surest paths to advancement. The 1853 culture was vastly different. The notion of a mathematics professor doing research was, literally, foreign. In the entire country only Strong and Benjamin Peirce, at Harvard, were committed to research. Stanley and Chauvenet had attained their standing by being knowledgeable and writing textbooks.

In 1853 no mathematics journal existed in the United States, nor was there any community of mathematicians, either locally or nationally. Nevertheless, societies promoting scientific scholarship functioned effectively at both levels. The Connecticut Academy of Arts and Sciences was established at the beginning of the nineteenth century. In Newton's time the Connecticut Academy was essentially a group of Yale faculty that periodically hosted scientific discussions in their homes. Linkage to a wider geographic community came in 1848 with the founding of the American Association for the

Advancement of Science (AAAS). The fourth AAAS meeting was held in New Haven in 1850, bringing to town the American scientific elite of Joseph Henry, Louis Agassiz, Alexander Dallas Bache, Benjamin Peirce, and Benjamin Gould.

Tutor Newton took advantage of these opportunities, participating in the activities of both the Connecticut Academy and the AAAS. In July 1853 he traveled to the semiannual meeting of the AAAS in Cleveland. There he met Benjamin Peirce. Newton described some work he had done in spherical trigonometry on the effect of the Earth's gravity on an orbiting body. The conversation with Peirce led to Newton's first publication [12]. The one-page paper, and a later revision, appeared in Gould's recently established *Astronomical Journal*.

In 1855 Newton, with this single publication, became the Yale Professor of Mathematics. At the age of 25 he was slightly younger than Stanley and Hadley when they received their permanent appointments. It is unclear what deliberations the administration conducted during the two years that elapsed after the original offer to Chauvenet. Perhaps they hoped that Chauvenet would change his mind, or possibly they were waiting to become convinced of Newton's suitability for the position.

The 1855 European Experience

There was little more that Hubert Newton could then do in the United States to reach the frontiers of mathematical research. The latest discoveries and their exposition were taking place in Europe. Although a transatlantic voyage was then a miserable two-week ordeal, it was not unusual for Yale students to make the journey for further study. In 1854 a few recent graduates were in Germany and writing back of their experiences. Letters from Europe circulated around the Yale campus [9]. The exotic descriptions of educational opportunities would naturally have made an impression on the ambitious Newton. The next step for him was to learn at the feet of the Parisian savants from his texts.

Fortunately for Newton there was a precedent. His predecessor Stanley had been permitted to defer his duties in order to study in Europe. Newton's request for a one-year leave was granted with the stipulation that the compensation for a replacement come out of his $1,600 salary [15, July 1855]. Newton planned his year of European travel to begin with extended study in Paris. Other Yale people had spent time in France, but their academic experiences were largely restricted to nonmathematical subjects at German institutions. Despite the limited information resources of 1855, Newton would have known some of the French names. Joseph Liouville held the mathematics chair at the Collège de France while Duhamel and Augustin Cauchy were among those giving courses at the Sorbonne. As might be expected, Newton encountered some surprises upon arrival. On November 28 he wrote to the Yale treasurer and librarian, Edward Herrick, with this update on his classes:

> For the last two months I have been at Paris waiting for the lectures to commence and employing the time quite profitably in learning the spoken language of France. The lectures commence two months later than I was informed—those at the Collège de France beginning next Monday. Of the 11 courses of scientific lectures at the Sorbonne but three or at most four are worth my while to attend. At the Collège de France there may be two or three more which would make about two lectures a day. I cannot remain here through these courses and how long I shall remain here after I have fairly seen and understood the men is yet to be decided.
>
> Chasles has done an excellent work in reducing to a system the modern labors in the higher Geometry. He has published a "splendid" treatise upon it and gives also an interesting course of lectures. Lamé lectures upon the Math. Theory of Heat and gives a very profound discussion of the subject. The lectures of Sturm and of Cauchy I have attended thus far for the two-fold reason—to see the men—and in hopes they would soon leave the elements. Duhamel, Lefébure de Fourcy, Delaunay—I have dropped [13].

Newton's enthusiastic report on Michel Chasles and Gabriel Lamé to Herrick contrasts with this gloomy excerpt from his letter the previous day to his college roommate John Brewer:

> This morning after taking a cup of coffee and a crust of bread (in France the bread is all crust) I considered more or less attentively some propositions in Geometrie Superieure until 10 o'clock when I took my breakfast. At 10 1/2 was a lecture. I was there 10 minutes late and waited five minutes for the prof. The lecture room does not compare with ours for comfort there being no backs for the seats and no alley so that to reach the front seats we walk down stepping on the seats. A clumsy arrangement that. The Prof. has so far been uniformly late. Perhaps his watch is slow. It must run too slow he finished about 1 3/4 hours after the time for the

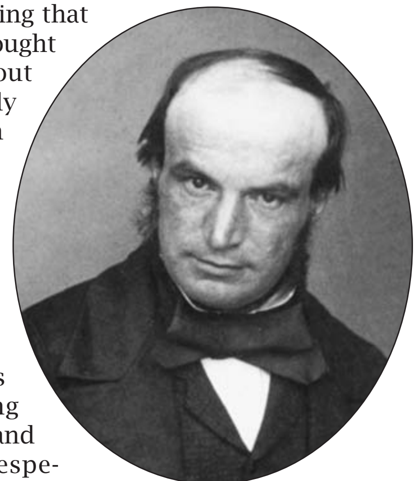
> beginning. But here he comes. He is a man about 65 a little more probably. He has a raw beefy looking countenance and his appearance otherwise is not much different as he need not be ashamed to place himself on the other beam of the scales from Mr. Skinner. He certainly does not give his personal countenance to the remark I have heard made that Mathematicians are spare and skeleton–like…he stands sideways. With one hand in his pocket he chalks out diagrams and formulas with the other. He never looks up at the class. I mistake, he did once look up and the expression was so ludicrous that we could not help laughing. In time he finished. That is at the close of one of his sentences without changing his manner or looking up he closed a book he had on the table walked towards the door and taking his hat stepped out while we waited to hear the next sentence. We looked at the spot where he disappeared then at each other then laughed then concluding the lecture was over disbursed. This lecturer is [obscured word] one of the greatest mathematicians in all Europe [14].

The obscured word in the last sentence is possibly "Sturm". At this time Sturm was just 52 years old, but three weeks from his death. Cauchy was 66.

Newton went on to describe more of his day. In the afternoon he watched the Emperor, Louis Napoleon, review his troops. The "pageant" of "helmets and plumes, cannon and bayonets, horses and men" made for a "sight [that] was truly splendid." Newton felt "fortunate in having witnessed the parade," but uneasy with his first close encounter with militarism. The "bayonets are the empire and make the peace of Paris. God grant we may never need (I will not say have) such an empire, or such a peace in America. …I am glad we have no army. I had rather enter upon a war unprepared if necessary than to support in peace as France does 500,000 men in going through unprofitable evolutions and tempting our powers that be to bring on a war."

Information on the remainder of Newton's year abroad is based largely on two subsequent letters to Herrick [13]. In February Newton went to England for three weeks. His description of this period is dominated by accounts of visits to observatories at Greenwich, Kew, and Cambridge. At Cambridge Newton enjoyed an informative conversation with the British astronomer John Couch Adams. Ten years earlier Adams had predicted the existence of the planet Neptune through calculations based on irregularities in the motion of Uranus. Ten years later Newton and Adams would both contribute to the prediction of meteor showers.

That Newton and Herrick shared an interest in astronomy provides some explanation for the extended discussion of this topic in the letters. Still it is striking that Newton so aggressively sought out telescopes throughout his trip. He had previously visited an observatory in Paris.



John Couch Adams

Photograph courtesy of the University of St. Andrews Library.

Newton went from England to Italy. The Italian itinerary included Rome, Naples, Florence, and Venice. Aside from an observatory in Rome, it seems that his activities consisted of sightseeing and viewing museums and galleries. Newton was especially impressed by Florence. In May he reached Vienna where he wrote his last letter to Herrick. At this point Newton was planning to remain in Vienna for at least a month, visit some German cities, and then return to America in August. He did make contact with fellow alumnus and tutor, Timothy Dwight, who was studying in Bonn and Berlin. In his own memoir Dwight, a future president of Yale, mentions that he and Newton were "traveling companions" for "a short time" [4, page 395].

Establishing a Research Program

With his return to Yale in 1856, Newton took up his duties as professor of mathematics. Meanwhile, inspired by Chasles' synthetic approach to projective geometry, Newton continued his own study of the subject. A key technique was the principle of polar inversion which transforms points and curves into other points and curves with similar intersection properties. Newton considered the problem of constructing a circle tangent to three given circles. If two of the given circles intersect, Newton employed the inversion approach to reduce to the situation of finding a circle tangent to another circle and two lines. Although the solution of the general case was already known, he had found a nice alternative construction.

As with the publication of his earlier paper on orbital mechanics, Newton's timing was fortuitous. For much of the nineteenth century there was no American mathematics journal. However, Newton's geometric discovery coincided with the founding of the short-lived *The Mathematical Monthly*. His solution to the circle problem appeared in volume 1. Two years later Newton followed up with a more substantial contribution to the third (and last) volume of the journal. This paper described and extended Chasles' intricate straight edge constructions for obtaining points on curves that are stipulated by certain specified data (such as a conic with given points, intersections, or tangencies).

Between the printing of the two geometry papers, Newton published an article on a different subject. In 1860 his "On the meteor of November 15th, 1859" appeared in the *American Journal of Science and Arts*. Others had previously provided detailed accounts of sighting the meteor from various eastern locations in the country. Newton collated the data and used triangulation techniques to calculate the visible path of the meteor. The underlying objective of his study was to infer the backward trajectory of the meteor's orbit. To do this he posited a lower bound for the body's velocity based on the observers' estimates of the time that elapsed while the meteor was visible. Newton then went further, making the dubious assertion: "The result of my investigation has been to establish almost beyond a doubt the conclusion, that *this body was not a member of the solar system but came to us from the stellar regions.*"

Publishing research, rather than textbooks, was very unusual for an American mathematics professor in 1860. Newton would continue to do so, writing over 40 papers on meteors and comets. He is best known for his work, described below, on the November Leonid showers. Meteors had long been the subject of considerable interest at Yale. The fascination began in 1807 when a bright overhead explosion of a meteor prompted Yale scientist Benjamin Silliman to perform an analysis on specimens recovered from the event. One decade later Silliman founded the *American Journal of Science and Arts*. A spectacular meteor shower on November 13, 1833, attracted the attention of professor Denison Olmsted and members of the Connecticut Academy. Silliman's journal became a vehicle for accounts of observations and for the proposal of theories about meteors.

Little was understood about the origin, mechanism, and orbits of meteors. Occasional shooting stars of varying intensities were well known to stargazers. What set apart the early morning November 13 event was the extraordinary sight of the sky filled with streaks over a two hour period. Olmsted set out to provide a scientific explanation for the phenomenon, publishing a long article about the shower in the *American Journal of Science and Arts* [16]. He began with verbatim eyewitness testimonies and followed with his own analysis. He noted that several observers, including himself, stated that all of the meteors seemed to originate from a common point in the sky toward the constellation Leo. The identification of this *radiant* was a significant step in understanding meteor showers.

Olmsted concluded that the shower was the result of the Earth coming into close proximity with a comet-like nebulous body that was moving in a different elliptical orbit about the sun. He set out to determine the ellipse, relying on a mistaken inference that the nebulous body was at aphelion (maximum distance from the sun) when meeting the Earth. Olmsted then looked for a feasible orbit that both intersected and was shorter than that of the essentially circular path of the Earth. In the investigation of the 1833 shower, historical accounts surfaced of a similar event in South America on November 12, 1799. One year earlier, on the same day in 1832, another shower had been observed from the Red Sea.

Olmsted pondered an elliptical orbit that revisited the same point after one year and 33 years. To accomplish the former he reasoned that the body must complete an integer number of revolutions each year. By Kepler's third law, for an orbiting body the cube of the length of its semimajor axis is proportional to the square of the period. Using units of years for the period and astronomical units for the semimajor axis, the proportionality factor is one for orbits about the sun. Since the semimajor axis must be at least one half for the orbit of the nebulous body to reach that of the Earth, the period must be greater than the square root of one eighth. But the period was assumed to be the reciprocal of an integer, forcing it to be at least one half year. Since he believed that the orbit was inside that of the Earth, Olmsted concluded that the period of the nebulous body was one half year.

Verification of Olmsted's theory could be provided by showers on subsequent annual anniversaries. Each November Olmsted enlisted a cadre of students and enthusiasts to watch the sky and record data on shooting stars. For the next several years possible recurrences were observed, albeit in much smaller and diminishing intensity. By 1838 even Olmsted had to admit that a shower probably had not occurred [17]. Still he continued the annual vigil. The thread arose in his 1850 correspondence with Newton. Olmsted arranged for his former student to observe the Sherburne sky on the morning of November 13 [10].

Olmsted died in 1859, about the time that Newton began his research on meteors. By then, Olmsted's six month period model was out of favor. In the intervening years showers had been observed in April and August. Intensive literature searches had identified occurrences in various months over the prior thousand years. The spread of data was confusing. Were all the showers linked to a single system? Some claimed that the phenomena originated from a terrestrial cause such as the weather.

Examining texts from the Middle Ages was challenging. To fix precise dates often required interpretation from contextual references such as the death of a king or a now obscure holiday.

After making these determinations and converting to the current Gregorian calendar, the years of the October-November showers were revealing. The showers clustered around the same three stages of each century. These were at the 0th year, the 33rd year, and the 66th year. For example, spectacular 1366 and 1202 showers were described in Portuguese and Arabic writings respectively. The pattern was strikingly consistent with the previously known instances of 1799, 1832, and 1833. The one problem was that the day of the month moved gradually with the year from November 13, 1833, to October 29, 1366, to October 26, 1202. The several-day variation required reconciliation with the notion of a fixed point of intersection from the Earth's orbit.

In 1863 Newton began to bring some clarity. Both the Gregorian and Julian calendars were based on the tropical year (going from solstice to solstice). Due to precession of the Earth's axis, the tropical year is about 20 minutes and 24 seconds short of the sidereal year which is calibrated by a complete revolution of the Earth about the sun. Thus every 70 years or so the hypothetical intersection node should move ahead a day. Newton converted the earlier shower dates to an 1850 sidereal scale and, for the events above, arrived at November 5, 1366, and November 4, 1202 [18]. These were closer to November 13, giving a stronger indication of some sort of periodic dynamic.

Newton put forward his model in 1864 [19]: an elliptical ring (annulus) containing the orbits of a nonuniformly distributed collection of small bodies that are concentrated over a small sector. The sun is one focus of the orbits, but the plane is slightly inclined to that of the Earth's orbit, and the motion is in the opposite direction. The Earth's orbit intersects the annulus. Showers occur in the years that the Earth passes through the loaded sector. Newton looked for a periodic orbit where intersections could happen for two or three consecutive years and then resume after a third of a century. Examination of the data indicated that the showers of 902 and 1833 occurred at about the same phase of a cycle. Dividing their difference by the 28 thirds (of a century cycles) they spanned, Newton adopted the assumption that each body returned to its original location after 33.25 years.

It remained to determine the ellipse and the prime period of the flow. Newton gave the following analysis: Configure the loaded sector to be centered at the intersection node z where the orbit meets that of the Earth. For each point x on the ring let $h_t(x)$ represent its position on the ring after t years. Now consider what happens after one year. To have another shower z must be in the loaded sector. So h_1 maps some other point of the loaded sector to z. Then $h_1(z)$ is near z, on one side or the other. During the year that z moves to $h_1(z)$, the orbit of z passes through the entire ring some nonnegative number of times. Kepler's third law limits the number of revolutions to less than three. Since $h_{33.25}$ is the identity, h_1 is either τ, $1 \pm \tau$, or $2 \pm \tau$ revolutions where $\tau = \frac{1}{33.25}$. The corresponding periods are 33.25 years, 354.6 days, 376.6 days, 180.0 days, and 185.4 days.

Newton argued that while all five periods were possible, 354.6 days was the most probable. He then offered this program to narrow the possibilities: Accurate coordinates for the radiant (which did not then exist) would permit calculation of a tangent vector to the ellipse and then the plane of the orbit. This information, together with a period and the intersection node, determine the orbit for the two body problem (in conjunction with the sun). Corresponding to each of the five hypothetical periods the perturbations due to the planets could, in theory, be computed. These results could then be compared with the known drift of the intersection point. Implementation had to wait for the next shower when a more precise identification of the radiant could be made.

Two years later, in 1866, a shower was seen in Europe on the morning of November 14. John Couch Adams, whom Newton had met earlier in Cambridge, then went to work on the hypothetical orbits. Adams showed that the four shorter paths were not feasible. However, the effects of Jupiter, Saturn, and Uranus on the highly elliptical 33.25 year period orbit summed to an excellent fit for the drift that Newton had computed [20].

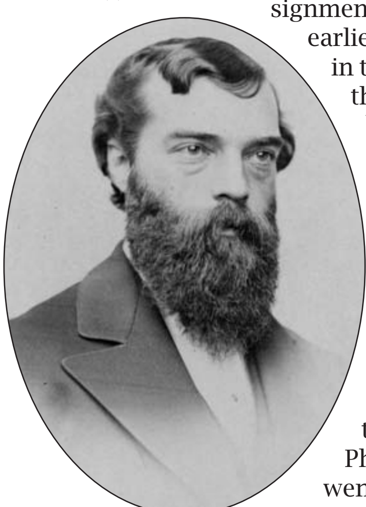
As Adams was performing the formidable calculations in 1867, Giovanni Schiaparelli reported that the bodies generating the annual August showers were in the same orbit as a comet first observed in 1862. It was subsequently determined that the Tempel-Tuttle comet was shadowed by the November meteoroids in its orbit [21]. The apparent one-to-one correspondence between comets and meteor showers raised a chicken or egg question which was not fully resolved until the middle of the twentieth century. Each time a comet approaches the sun, particles from it are ejected into nearby clumps. It is the bodies of these dust trails that produce meteor showers when they enter the Earth's atmosphere. Today, supercomputers track the spread of the orbiting dust trails, projecting future encounters with the Earth [22]. The name for the November shower, Leonid, follows the convention of derivation from its radiant.

First Mathematics Ph.D. in the United States?

As Newton began research on meteors, he participated in one of the landmark events of American higher education. In 1860 Yale became the first institution in the United States to offer the doctor of philosophy degree. All Yale bachelor's graduates were eligible to become candidates, as well as others meeting additional conditions. Requirements for the Ph.D. consisted of two years of study from at least two branches of learning, a final examination, and "a thesis giving evidence of high attainment in the branches they have pursued" [8, 1860–61].

At the 1861 Yale graduation, on July 25, Eugene Schuyler, Arthur W. Wright, and James Whiton received the first Ph.D.s ever awarded on American soil. Those in attendance could not have anticipated how many institutions would adopt their own doctoral programs. As might be expected, many of today's conventions were not yet in place. For example, neither subjects nor advisors were associated with the individual awards.

Separate departments such as physics, Latin, or history did not then exist at Yale. Newton, as the professor of mathematics, was a member of the Academical Faculty as well as serving in the Department of Philosophy and the Arts, the umbrella grouping that administered the new degree. In the twentieth century, with partitioning into disciplinary departments, retrospective assignments were made of subject areas to earlier degree conferrals. Doubts arose in these determinations under which the "guiding principle" was to have been the "subject of the dissertation" [23]. While not all dissertations, or even their titles, had survived, in most cases there was considerable information about the subsequent career of the recipient.



Arthur W. Wright.

Under this process, John Worrall (in 1862) and Charles Rockwood (in 1866) were identified as the first recipients of Ph.D.s in mathematics [24]. Both went on to careers in mathematics education. Worrall taught at various levels in West Chester, Pennsylvania. Rockwood became a mathematics professor at Bowdoin, Rutgers, and then Princeton. Rockwood's thesis was "The Daily Motion of a Brick Tower Caused by Solar Heat". The title of Worrall's thesis is unknown.

Arthur W. Wright was among the three students who finished one year prior to Worrall. Wright's dissertation was entitled "Having Given the Velocity and Direction of Motion of a Meteor on Entering the Atmosphere of the Earth, to Determine its Orbit about the Sun, Taking into Account the Attractions of Both These Bodies". Given that Wright served over thirty years as a physics professor at Yale, it is not surprising that his 1861 Ph.D. was deemed to have been in physics. With further hindsight, there is a strong argument that Wright's degree was actually in mathematics.

Wright received his B.A. in 1859 and began graduate work at Yale. At this time physics was

Wright's Ph.D. diploma.

covered by the professor of natural philosophy and astronomy. With Olmsted's death, the chair was vacant during Wright's first year of graduate study. In 1860 Elias Loomis succeeded Olmsted. The previous year Chester Lyman became professor of industrial mechanics and physics for the Scientific School. The Scientific School was a separate division of Yale that had been formed around the applicable sciences. Members of its faculty also served in the Department of Philosophy and the Arts. Wright was examined on his studies in mathematics, modern languages, mineralogy, and botany [25].

Classifying Wright's thesis among the fields of astronomy, mathematics, and physics runs into the difficulties of ill-defined subject boundaries and overlaps, both of which have shifted over time. It is unfortunate that there are no extant copies of the thesis. Analysis must devolve to the title and must be placed in the context of the contemporary research scene. Meteors were not then a topic in the mainstream of American astronomy. However, astronomy was a most active area of mathematics in general and American mathematics in particular. Benjamin Peirce worked on the orbit of Neptune. The third and fourth presidents of the American Mathematical Society, George Hill and Simon Newcomb, specialized in celestial mechanics.

Newton published papers on meteors in every year of the 1860s. Loomis' limited study of meteors came much earlier in his career. Lyman was more interested in the observational and equipment aspects of astronomy. The title of Wright's thesis places the work at the heart of Newton's current interests. Newton almost certainly served in the, not yet defined, role of Wright's thesis advisor. Considering the examination areas, thesis topic, and faculty of the time, Arthur W. Wright should be regarded as the first student to receive a mathematics Ph.D. in the United States.

Wright maintained his interest in meteors. Newton's 1863 meteor observation reports cite Wright as a partner or teammate. At this time Wright held the title of tutor. Over the next several years he taught Latin and physics to undergraduates. After a year of study in Germany and a professorship at Williams, Wright joined the Yale faculty in 1872. He was professor of molecular physics and chemistry until 1887 when the designation of his chair was changed to experimental physics.

The research interests of Wright and Newton continued to overlap. Wright analyzed occluded gases in meteorites and drew implications on the relation between comets and meteoroids. Later he became a pioneer in X-ray experiments and was known for his work on "the deposition of metallic films by the cathode discharge in exhausted tubes" [26]. In 1881 Wright was inducted into the National Academy of Sciences. He died in 1915 at the age of 79. The A. W. Wright Nuclear Structure Laboratory at Yale honors his memory.

Gibbs and Moore

By all indications Newton was an effective mentor. J. Willard Gibbs was the Yale salutatorian in 1858 and E. H. Moore the valedictorian in 1883. Both won undergraduate mathematics prizes, obtained Yale Ph.D.s, studied abroad, and went on to have an enormous impact on scientific scholarship. Their careers were also shaped, in the formative years, by the influence and support of Hubert Newton.

Gibbs was raised in the Yale community [27]. His father, also named Josiah Willard Gibbs, was a sacred literature professor who died in 1861. Willard, the son, was then in graduate school. He passed examinations in mathematics, ethics, and modern languages. There remains some doubt surrounding Willard's thesis. After his death, a manuscript entitled "On the Form of the Teeth of Wheels in Spur Gearing" was found among his papers. Those associated with the university concluded it to be Gibbs' 1863 thesis. Accordingly, Willard Gibbs' Ph.D. is listed as in engineering.

After completing his degree, Gibbs was appointed to a tutorship. During this period, and possibly earlier, he was involved in Newton's research on meteors. In Newton's 1864 Leonid orbit paper, Gibbs is the one person acknowledged for valuable suggestions. In particular, Newton singled out his help with a delicate aspect of narrowing the periods. Their relationship is especially notable in view of Gibbs' social isolation.

Willard and his two sisters, Julia and Anna, lived the rest of their lives together in the house left to them by their father. Only once did Willard venture far from New Haven. In 1866 the three siblings sailed for Europe where he would study in Paris, Berlin, and Heidelberg. Gibbs set out in Newton's footsteps, taking courses at the Sorbonne and Collège de France from Chasles and others. Over the summer the Gibbs were met by Addison Van Name, the valedictorian from Willard's class who was engaged to Julia. The couple were married in Berlin and returned to New Haven. Anna remained with Willard in Germany. Over the next two years he studied mathematics and physics from professors that included Weierstrass, Kronecker, and Magnus.

The trip to Europe stands out as one puzzling aspect of Gibbs' insular life. Transatlantic travel and study in those days required a sort of initiative that otherwise appears to have been absent in Gibbs. The course with Chasles indicates a connection to Newton. It is reasonable to speculate that Newton played some role in persuading Gibbs to take advantage of the resources abroad.

J. Willard Gibbs.

Photograph from the Beineke Rare Book and Manuscript Library.

In 1869 Willard and Anna returned to America and joined the Van Names to form a household. Only Addison, as Yale librarian, was employed. Willard continued his independent study. The household was supported by Van Name's salary and the Gibbs' inheritance. Newton was a neighbor. The Newton children recalled Gibbs as a daily visitor, discussing science with their father [28].

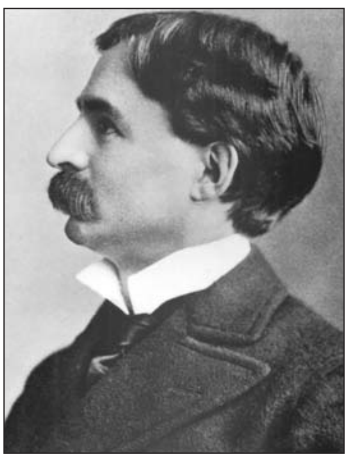
During 1871 Yale was in a period of transition between presidents. A committee that included Newton and Van Name produced a report entitled *The Needs of the University*. Among the recommendations were an infusion of new funding and the creation of additional chairs in physics and other subjects. Newton was the only member of the committee with expertise in mathematics and physics. Shortly after the report was issued, Willard Gibbs was appointed as professor of mathematical physics in the Department of Philosophy and the Arts. The position carried no salary. Essentially it was a research professorship that would involve a small amount of graduate teaching.

The exclusion of undergraduate teaching was understandable in that Gibbs had unfavorable reviews as a tutor. Still, the appointment of an unpublished scholar involved considerable risk to the parties at both ends. Yale was conferring its imprimatur, and Gibbs was embarking on an uncertain path with dim financial prospects. Whatever role Newton had in choreographing this relationship, the returns were immediate and far-reaching. From 1873 to 1878 Gibbs published his seminal work that established a thermodynamic foundation for physical chemistry. Recognition came slowly, and he remained without a salary until 1880. Johns Hopkins then offered a professorship with a $3,000 salary. Yale countered with

$2,000. Gibbs remained in New Haven where he died in 1903.

The founding of the Johns Hopkins University in 1876 changed forever the landscape of United States scholarship. A few other universities had commenced doctoral programs, but, at Hopkins, research and graduate education were the priorities. Moreover, its president, Daniel Coit Gilman, secured the personnel to implement his vision in mathematics, physics, and other subjects. Gilman had graduated from Yale two years after Newton, traveled through Europe, and then returned to his alma mater becoming a member of the Scientific School faculty. He had served with Newton and Van Name on the needs of the university committee but left Yale shortly after a more conservative colleague was selected over him as president.

When E. H. Moore received his Ph.D. from Yale in 1885, mathematics was germinating in the United States. However, Europe remained the center for important investigations. As Moore's thesis advisor, Newton foresaw how Moore's talents would be cultivated by further work in Germany. Newton facilitated Moore's study abroad by loaning him money to spend a year "at Göttingen and Berlin for a promise to pay at some future time" [29].



Photograph from the AMS archives.

E. H. Moore.

Moore attended lectures by Kronecker and Weierstrass, prior to beginning an academic career in the United States. His first lower level positions were at Yale and Northwestern. Despite the arduous teaching loads, Moore continued his research and publication. His real opportunity came in 1891 when Yale Divinity Professor William Rainey Harper became the founding president of the University of Chicago. At Chicago, Harper would bring about the biggest advance in American scholarship since the creation of Johns Hopkins. As had Gilman before him, Harper put considerable effort into recruiting a faculty suited to carry out his plans.

Harper's choice of Moore to lead mathematics contrasted sharply with the experienced scholars selected to head other departments. Moore was an assistant professor at Northwestern which did not then have a doctoral program. While Harper was no doubt impressed by Moore from their interactions at Yale, mathematics was a subject outside Harper's expertise. As Moore's advisor and Harper's colleague, Newton was ideally positioned to supply a decisive endorsement (no record of any evaluation has been found).

At Chicago, Moore's career flourished [2]. An appreciation of mathematical developments in Germany influenced his research, teaching, and administration. To complete his staff Moore hired the German émigrés Oskar Bolza and Heinrich Maschke. Chicago became the first American university to offer mathematics training at the level and breadth available in Europe. Moore himself supervised the theses of Leonard Dickson (1896), Oswald Veblen (1903), and George D. Birkhoff (1907) who became the leading mathematicians at Chicago, Princeton, and Harvard respectively. Their descendents included Adrian Albert, R. L. Moore, Alonzo Church, Marston Morse, Marshall Stone, and Hassler Whitney.

In 1899 the University of Göttingen awarded an honorary Ph.D. to E. H. Moore. Over the early twentieth century Moore and his progeny were at the forefront of the stunning ascendence of American mathematics. Moore's contributions went beyond paternity and his own research. It was largely through his initiative that the New York Mathematical Society became, both in name and character, the American Mathematical Society [30]. Moore was a driving force behind the start-up, in 1900, of the *Transactions of the American Mathematical Society*. Under Moore's painstaking editorship the journal showcased the excellent research produced in America. In just one half century, the United States had advanced from a backwater to a font of mathematical scholarship.

The 1896 Generational Change

Hubert Newton is known to mathematicians of today, if at all, as the thesis advisor to E. H. Moore. During his lifetime, however, Newton was one of the most honored mathematicians in the United States. In the 1860s he was inducted into the American Academy of Arts and Sciences, the National Academy of Sciences, and the American Philosophical Society. In 1868 Newton was awarded an Honorary Doctor of Laws by the University of Michigan. Twenty years later he received the J. Lawrence Smith Gold Medal from the National Academy of Sciences. Other recognitions included foreign membership in the Royal Society of London and the 1885 presidency of the American Association for the Advancement in Science.

Newton's resumé was not that strong in 1863 when President Abraham Lincoln signed the law to establish the National Academy of Sciences. Two weeks earlier Louis Agassiz, Alexander Bache, Benjamin Peirce, and Benjamin Gould had met with Senator Henry Wilson to consider an Academy proposal conceived by Captain Charles H. Davis [31]. Out of this meeting came the draft of the legislation which was to sail through the Congress. The purpose of the organization was twofold: to assist the government on matters requiring scientific expertise and to recognize investigators who had made significant advances.

The bill named 50 men for inclusion in the National Academy. The old boy selection process and the low level of American science led to a loose interpretation of the standard for original research. Recall that Yale began to award the doctoral degree just one and one half years earlier. Mathematicians joining Newton on the incorporating list were Peirce, Chauvenet, and Strong. They were the leading names of the time. The early influence of the National Academy was limited. Committees advised on a variety of maritime and other issues. Newton participated in an unsuccessful initiative to advocate adoption of the metric system. Over the Academy's first decade, Strong and Chauvenet died. Peirce resigned in 1873 in a dispute over the exclusivity of membership [31, page 119].

Newton, the youngest of the four mathematicians, was the last to die. His death, in 1896, occurred as Moore's first student completed his Ph.D. A transition was taking place in American mathematics. The most prominent senior mathematicians were Hill and Newcomb. Both worked in astronomy and were domestically educated without a Ph.D. The rising stars were Moore, William Osgood, and Maxime Bôcher. Osgood and Bôcher had done their undergraduate work at Harvard and traveled to Germany for their Ph.D.s. Moore completed his formal education at Yale but needed to go abroad to prepare for a research career. Moore's student, Leonard Dickson, had received a complete graduate education. Although Dickson did spend the following year in Leipzig and Paris, the European experience was no longer an essential ingredient in the training of American mathematicians. Birkhoff did not travel to Europe until 1926, thirteen years after he achieved international renown with his proof of Poincaré's last geometric theorem. It is fitting, and no coincidence, that Newton's lifetime spanned the struggle of the United States to become self-sufficient in mathematical research.

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