American physics and the origins of electrical engineering

Pure physics applied: academic physics gave birth to a new practical discipline with its own priorities and its own departmental structure.

Robert Rosenberg

At the same time that electricity was transforming American society in the last half of the 19th century, it was transforming the study of physics. During this period, electricity bridged the existing gap between pure science and useful applications, between thinkers and doers, scholars and tinkers, as no other technology had done before. It brought home to Americans the contributions of science to everyday life. It also quickened the pace of physics research in university classrooms and industrial laboratories.

Together, electricity and physics held immense promise for the future—a promise unnoticed at the Philadelphia centennial exhibition of 1876, with its small displays of telephones and dynamos, but visible to all at the opening in 1883 of the Brooklyn Bridge, illuminated by the new incandescent electric lights developed by the Wizard of Menlo Park, as the newspapers of the time referred to Thomas Alva Edison. It happens that both dates are reference points for US physics. In 1876, Henry Augustus Rowland, educated as an engineer but dedicated to basic research, became the first professor of physics at the newly founded Johns Hopkins University in Baltimore, and, in 1883, Rowland proclaimed in his vice-presidential address to the American Association for the Advancement of Science that henceforth the word "science" should no longer be applied to the telegraph, telephone, electric light or electric motor. With the advent of electrical technology, American physicists could choose to be theoretical or practical—or both.

The connection and then disconnection of basic physics and electrical engineering had been made years earlier in Europe. In Britain, such theorists as James Clerk Maxwell and John William Strutt (Lord Rayleigh) at Cambridge University had a great impact on technology, but their immediate influence was indirect since few engineers could understand them. It took a creative effort almost equal to that of Maxwell and Rayleigh by Oliver Heaviside, a British engineer with no formal education past the elementary level, to translate their electromagnetic equations into a usable form, and even Heaviside's work was unintelligible to most engineers. Yet Maxwell and Rayleigh were among those physicists who consciously attempted to contribute to technology. Others include Heaviside's uncle, Sir Charles Wheatstone of King's College, London, who somewhat anticipated Samuel F. B. Morse in developing the telegraph, and William Thomson (Lord Kelvin) at Glasgow, who virtually single-handedly engineered the cables, galvanometers, and other electrical components for the first successful telegraph cable beneath the Atlantic Ocean in 1866.

By the 1880s, the need for rigorous training in electrical engineering was becoming clear to many. Werner Siemens, Germany's leading industrialist of the period, urged his country's technical schools to introduce courses in electrical engineering and, with a leading physicist, Hermann von Helmholtz, he persuaded the government to establish a national laboratory in 1882. Around that time, William Ayrton attempted to organize in London the sort of laboratory instruction in electricity that he and John Perry had carried on in the late 1870s at Japan's Imperial College of Engineering.

Electrical innovations

Such examples did not go unnoticed in the US, though the order of events was somewhat different. By the late 1870s, the considerable body of knowledge produced by rapidly advancing research on electricity in Europe had crossed the Atlantic, and by the end of the century electric innovations in the US had provided an ineluctable justification for supporting physics teaching at universities and research work in companies. In the US it was not the physicist—such as J. Willard Gibbs at Yale or Henry Rowland at Johns Hopkins—who caught the public imagination, but the inventor—Edison, Charles Steinmetz, Nikola Tesla—working in commercial surroundings.

The success of electrical technology

Robert Rosenberg, a doctoral candidate in the History of Science Program at The Johns Hopkins University, has been recently appointed a research associate on the Edison papers project at Rutgers University.

0031-9228 / 83 / 1000 48-07 / $01.00

Electrical engineering students at Cornell's Sibley School in the 1890s learning about the design of street railway motors. Subject of study is written on blackboard at rear of class. (Courtesy Cornell University Archives.)

had two effects on American physics. First, students eager to understand the new electrical technology and to contribute to it, as well as to profit from it, put an unceasing strain on the budgets and facilities of physics departments in universities, colleges, and technical schools. Of some 400 colleges and universities surveyed by T. C. Mendenhall for the US Bureau of Education in 1882, almost all offered some instruction in physics, but only 20 had even minimal laboratory facilities. In the many large physical laboratories built during the 1880s, the lion's share of space was devoted to the study of electricity and magnetism.

Second, the social impact of electrical technology confirmed the claim of physicists that their investigations led to material progress. In 19th-century America, this was an important point. Chemistry had already demonstrated its utility in agriculture and industry, and biology was linked with medicine, but until the growth of electrical technologies, physics held little claim to being utilitarian. The source of the new technologies was in research, both pure and not so pure.

Dynamo as symbol

As long as it emphasized power and light, electrical engineering needed a solid foundation of physics and mechanical engineering. It is somewhat surprising, then, that early electrical engineering education was under the direction of physics teachers. Mechanical engineers did not involve themselves because in the early 1880s mechanical engineers did not understand electricity. Thus, although a paper presented in 1882 to the American Society of Mechanical Engineers on the Edison Steam Dynamo—the combination steam engine and dynamo that was to power the Pearl Street Station in New York City—treated both components of the machine, the lengthy discussion that followed was entirely about the steam engine. One prominent engineer, puzzled by the working of the dynamo, said, "There may be electrical reasons for this construction." What those reasons were, he had no idea.

Mechanical engineers recognized (and laughed about) the mechanical ignorance of many electrical engineers, and sometimes referred to Sir William Thomson's dictum that an electrical engineer should be 90% mechanical and 10% electrical. Until the end of the 1880s, however, when electric motors began to compete successfully with steam as a power source, mechanical engineering as a profession had little to do with electricity. By the time the mechanical engineers became concerned about the encroachment of electric power, the electrical engineers had their own discipline, their own professional image, and their own ideas about how to educate students.

In the early 1880s, the need for formal education in electrical engineering was becoming manifest. The editor of *The Electrician*, a New York trade journal, wrote in April 1882:

> There is now a rapidly growing want for men trained in the theory and practice of the science of electricity.... The demand is established, and it now behooves our foremost educators to devise a means of satisfying it.

An American just back from Europe wrote a letter to the student paper at Cornell in September 1882, urging undergraduates to consider the new profession of electrical engineer now being taught abroad.

> The enormous extension of the telegraph, telephone, electric light, etc., into all parts of the world will create a great demand for skilled electricians at no very distant day.

To which the editors added,

> We wish to recommend this specially to the students of Cornell University as a department well worthy of their careful investigation.

That fall, Edison wrote to the president of Columbia College suggesting that a course in electrical engineering should be given in the School of Mines and offering his electrical collection to the College as a museum.[1] Although Edison often publicly belittled academics and universities, he employed physicists, chemists and metallurgists and even consulted with college professors and read scientific journals. During the 1880s he contributed many thousands of dollars in equipment for electrical engineering programs at several schools. Columbia did not establish a course in electrical engineering until the end of the decade, by which time most universities were already actively teaching electrical science in their physics departments.

First course in EE

The first formally structured course in electrical engineering appeared in 1882. But the roots of that course were embedded in the 1870s, when such academic physicists as Charles Cross at MIT and William Anthony at Cornell began to shape their teaching around the new discoveries in electricity.

In 1869, Edward C. Pickering, professor of physics at MIT, established the first systematic laboratory instruction in physics in the country.[2] In the 17 classes preceding the initiation of the electrical engineering course at MIT, only six of the 361 graduates took degrees in physics. The reason for the lack of interest in a physics degree is not hard to ascertain. It could be found in MIT's 1881–1882 catalog (and had been noted by Rowland at Johns Hopkins four years earlier): "Most of the students taking the course in Physics intend to make teaching their profession." Unfortunately, there were few openings for physics teachers in the 1870s and early 1880s.

Cross had graduated from MIT in 1870, one of a class of ten, the only student in the General Science and Literature course. He at once became an instructor in the physics department, a professor in 1874, and head of the department on Pickering's departure in 1877. Cross had an intense interest in electricity. In his 1873 report to the president of the Institute, he noted:

> The most defective portion of the apparatus designed for lecture-room use is that relating to electricity and magnetism, upon which a considerable sum must be spent in order to make it a fair representation of the present state of electrical science.

The next year some electrical apparatus, including an induction coil, was obtained by the department, and the electrical inventor Moses Farmer loaned the Institute one of his magnetoelectric machines. In 1876, six electrical experiments were offered in the laboratory. The same year, Cross hired Silas Holman of the class of 1876 (in physics) as a laboratory assistant. Holman was an important part of the physics department for more than 20 years, contributing greatly to the electrical engineering program.

By the spring of 1878, electrical questions were appearing on examinations for second-year students of physics. Examples:

> What is a Thomson's galvanometer and what advantages has it over the ordinary form?
>
> What is a commutator?
>
> What is a shunt, and when used?

The next year, the first-term examination for the juniors had a question on Ohm's law. Four of seven questions on the same examination one year later (in January 1880) dealt with electrical subjects—the theory of the voltaic cell, Lenz's law, Ohm's law, and the operation of induction coils, telegraphy and dynamos.

In 1881, the MIT catalog announced:

> On alternate years a course of lectures will be given upon the scientific principles involved in the more recent applications of Electricity including the Telegraph, the Telephone, Electric Lighting, and the transmission of power by electricity.

The next year, with the addition of "an extended course of Laboratory instruction in electrical measurements," the lecture course became the senior-year instruction in the new "alternative course in Physics . . . for the benefit of students wishing to enter upon any of the branches of Electrical Engineering." Two years later the course would be formally called Electrical Engineering, but with no significant change in content. In fact, the establishment of the "alternative course in Physics" in 1882 involved little more than the shuffling of existing courses to effect a marriage of physics and mechanical

Henry Rowland of Johns Hopkins, one of the leading US physicists, in a portrait by one of the nation's greatest artists of the period, Thomas Eakins.

engineering. It was just the next step in a natural evolution, rather than a restructuring or redirecting of Cross's teaching.

At MIT, electrical engineering instruction kept the physics staff busy. Electrical engineering students had as much physics as the physics students and then some. In the first year of the course, 18 students were registered, and in the second year, 30. In successive years, it continued to grow, and in 1889 was the best-attended program at the Institute, with 105 students. Moreover, in 1891, some 23 students graduated in electrical engineering, while only three took physics degrees. In 1896, electrical engineering degrees were given to 48 students, while the number receiving degrees in physics was still three.

At Cornell, much the same evolution was taking place. Anthony had come to Cornell in 1872 with a high reputation in physics. When Anthony was hired away from the Iowa Agricultural College, Cornell's vice-president William C. Russel told the university's president, Andrew D. White, that the school had acquired a "tower of strength."[3] Anthony was an exceptional teacher and an adept experimentalist, and kept himself fully informed on current developments in his science. He possessed the idealism of a pure scientist and the practical bent of an engineer. The prospect of a position at Cornell was enticing. He wrote to Russel in 1872:

> I judge that your standard of scholarship is higher [than at Iowa], and that your aim is to make *scholars*, as well as impart "practical" knowledge. I want to get into an atmosphere where the grandeur and beauty of scientific truth are recognized and where science is valued for *itself*.

In 1873, after enumerating for White the many possible uses for physics in the modern world, he added:[5]

> But I should not consider the teaching of the practical application of physics to be the highest purpose of the physical laboratory. I should hope that young men would be found who would wish to pursue the science for its own sake. I should wish to furnish to such an opportunity to make investigations that would advance the interests of science.

To further this end, Anthony had made his acceptance of the job conditional on the university's purchase of at least \$15 000 worth of apparatus in his first five years there.[6]

Three illustrious physicists of the late 19th century (clockwise from top left), William Anthony of Cornell (photo courtesy Cornell University Archives), his successor, Harris J. Ryan (Cornell College of Engineering), and Edward Pickering of MIT (with muttonchop whiskers), who was photographed here on an outing with academic colleagues (Hale Observatory, Courtesy AIP Niels Bohr Library).

Funding problems

Had Cornell not fallen on hard times in the 1870s (as did MIT and many other institutions), the physics department might have achieved prominence earlier than it did. Certainly Anthony's career there would have been quite different. As it was, in the spring of 1873 Anthony had to give a course of popular lectures during vacation to raise money for apparatus, and when he resigned 14 years later it was partly out of frustration at being denied \$1500 for instruments.

But although financial embarrassment was a hindrance to Anthony's department, the development of electrical science was tremendously stimulating. Anthony's interest in electricity was even more precocious than Cross's. In 1872, years before any commercial installations, Anthony already hoped to acquire an "electromagnetic machine for producing the electric light" to illuminate his lecture room.[7] The next year, as part of a wish list of practical experiments for students to perform in the laboratory he did not have, Anthony included[8]

> Electrical measurements. Measurements of resistance and insulation, power of batteries, location of faults. Measurements of electromagnetic power, with reference to electromagnetic machines and motors.

The inclusion of motors was remarkably farsighted, for in 1873 the development of electric motors was barely under way—for the most part in Europe.

The next year, unable to get a Gramme dynamo from Europe, Anthony built one with the help of a student at Cornell and a machinist from Ithaca. The machine was a tribute to Anthony's talent, and became an early symbol of Cornell's eminence in electrical science. It was exhibited at the Centennial Exhibition of 1876, and on its return to the Ithaca campus it was used to power two arc lights, wired through underground cables of Anthony's design and manufacture. This was the first such permanent installation in America. The dynamo was used in the laboratory through the first decades of the 20th century, and is still in working condition today. By the early 1880s, electricity was occupying most of Anthony's time. Mechanical engineering undergraduates were writing theses on electrical topics under Anthony's supervision, and in early 1883 he was asked to draw up a curriculum for an electrical engineering course. Approved by the trustees and faculty, the course was offered that fall in the physics department.

Cornell's undergraduate degree program in physics had been no more popular than MIT's. In the ten years after 1876, only 13 students earned physics degrees out of a total of 678 undergraduate degrees awarded at Cornell. The student paper reported in 1876 that three-quarters of the undergraduates in scientific courses planned to be lawyers, physicians, ministers or journalists; the rest teachers, merchants or manufacturers, and "a very few, scientists." Although few students pursued a physics degree, some physics was required of nearly all students. This was also true at MIT.

By 1880, Anthony was irritated by crowding and the lack of laboratory apparatus. He told officials at Cornell that the department was "20 years behind the times."[9] That year the administration granted him his laboratory, and he requested a lecture room with 200 seats. Ten years later, the number of undergraduates in electrical engineering numbered 218—more than could fit in the lecture hall at one time.

In 1885, Anthony built an enormous tangent galvanometer, an instrument of extraordinary precision and utility. It represented the direction of the department: After 1882, almost all of Anthony's requests for appropriations concerned electrical apparatus. Defending one such a request in 1886, he protested:[10]

> Is it to be supposed that, in 1872, I should have foreseen the demand that would be made by the extraordinary growth and the vast importance of the industrial applications of electricity? Is it to be wondered at that I should see possible ways of improvement now that I did not see then?

Unfortunately for Anthony, the sympathetic Andrew White had been succeeded as president in 1885 by the less scientifically inclined Charles K. Adams, who would only later learn to appreciate the place of technical studies in the university. Anthony's 1886 request was denied—repeatedly. Frustrated, he left Cornell in 1887 to take a position as consultant to an electrical manufacturer.

He suggested as his successor Edward L. Nichols, who would become a leader not only at Cornell, but in American physics as well. Anthony called him[11]

> the best man I know to make a success of the Physical Department here in the directions both of pure science and its practical applications.

Nichols was a Cornell graduate who had spent four years in German laboratories, one year with Rowland, another year with Edison, two years teaching in Kentucky, and four years teaching at the University of Kansas. In his last year at Kansas, Nichols had prepared an electrical engineering course for the fall of 1887.

Nichols taught electrical engineering courses in his first year at Cornell. In the spring of 1888, however, an independent department was set up within the Sibley College of Engineering, with an associate professor of electrical engineering given responsibility for teaching "the construction of engineering work . . . peculiarly appertaining to electricity." By the end of the 1880s, the proper education of an electrical engineer was beyond a physics department. The new programs were run by electrical engineers with practical experience and scientific sophistication. Even so, physics departments were required to teach young electrical engineers the scientific fundamentals.

One of Anthony's prize students had just such training. Harris J. Ryan was a member of the first formally admitted class in electrical engineering and was Anthony's assistant. A year after his graduation in 1887, Ryan became an instructor in physics, an later the principal figure in the electrical engineering department.

Flourishing of EE

Although Cornell and MIT deserve special attention for establishing two of the earliest and most respected programs in electrical engineering, they did not have the field to themselves for long. In the same year that Cornell introduced its program, 1883, the Stevens Institute in Hoboken, New Jersey, began a course in Applied Electricity. A number of schools acknowledged the rise of electricity with subcourses in their physics departments—among them Lehigh in 1883 and Rose Poly-

Class of 1890 electrical engineering graduates, in frock coats and bowler hats, adorn stairs at MIT, then located in Boston's Back Bay, for a classic photograph of their halcyon days as students in a burgeoning field. (Photo courtesy Archives, California Institute of Technology.)

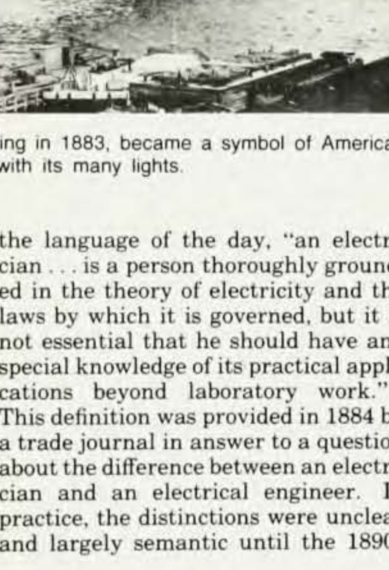
BETTMANN ARCHIVE

Brooklyn Bridge, pictured just before its opening in 1883, became a symbol of American ingenuity, heralding the new era of electricity with its many lights.

technic and the Lawrence Scientific School at Harvard in 1884. The first two were well-attended, but the Harvard program was little more than a title in the catalog until the 1890s and even then was weak. By that time, electrical engineering programs existed in name, if not in fact, in schools throughout the country.

At the 1884 International Electrical Exhibition, Henry Rowland declared: "It is not telegraph operators but electrical engineers that the future demands." Accordingly, in 1886, he established a program in applied electricity at Johns Hopkins to train electrical engineers, and enrollment soon outgrew the new physics building. But when Hopkins's finances went sour in the 1890s and no outside sponsor could be found for the program, the subject was withdrawn.

Interest in the new technology reached into the Hopkins physics department itself. Rowland's first PhD recipient, William Jacques, given his degree in 1879, went to work immediately for American Bell telephone company as an "expert," a job that had not existed when Hopkins had opened its doors three years earlier. During the 1880s and 1890s, quite a few graduate students were admitted to Rowland's laboratory with the express purpose of gaining familiarity with electrical science. Many of them left to work in the industry. Rowland himself reigned for two decades in a dual role as America's foremost pure physicist and as America's foremost electrician. In the language of the day, "an electrician . . . is a person thoroughly grounded in the theory of electricity and the laws by which it is governed, but it is not essential that he should have any special knowledge of its practical applications beyond laboratory work."[12] This definition was provided in 1884 by a trade journal in answer to a question about the difference between an electrician and an electrical engineer. In practice, the distinctions were unclear and largely semantic until the 1890s when electrician began to assume its modern meaning—someone who can wire a house or fix an appliance—and electrical engineers became more particular about being called by their proper title. Rowland and other prominent physics professors—among them George Barker at the University of Pennsylvania, Henry Carhart at Michigan, and Cyrus Brackett at Princeton—had close ties to the commercial development of electricity as consultants and legal experts in patent squabbles.



JON REIS

Advancing truth and beauty

Besides stimulating departmental growth in the schools, electricity gave American physics research a utilitarian justification it had never before possessed. In 1876, at the time of the founding of Johns Hopkins, the champions of American physics numbered a mere handful. Besides those few physicists lucky enough to be in teaching positions or government service, the supporters were found primarily among the most educated in society. This group prided themselves in upholding high standards of culture. For them, those who pursued pure science were somehow ennobled as the vanguard of American civilization; they considered the study of physics the moral equivalent of the antebellum study of the classics. The discipline of the laboratory, enforced by Natural Law, they argued, would replace the discipline of conjugation and declension, enforced by the dusty pedant, and the beauty of Nature's Truth would excel the beauty of Homer and Horace. Although this group was also loud in proclaiming that disinterested, pure research was the basis of technological advance, their hearts were in the battle against the corruption and materialism of the Gilded Age. But the practical success of physics in the 1880s and 1890s was evident to all. Public and industrial reliance on electricity and the fortunes spawned by electrical products made the "physics as culture" argument unnecessary and obsolete.

The passion for practicality—and the concomitant lack of interest in the development of theory—had long been part of the American experience. Alexis de Tocqueville recognized this American trait in the 1830s and deplored it, maintaining that hardly anyone in the new nation was devoted to pursuing knowledge for its own sake. When John Tyndall lectured through the eastern states in 1872–73, he made a strong plea for the support of research and implored Americans to prove de Tocqueville wrong. In 1876, the astronomer Simon Newcomb bemoaned the nation's pitiful contributions to abstract science. Thus, when Henry Rowland stood before the physical science section of the AAAS in 1883 to deliver his celebrated "Plea for Pure Science," he was voicing frustrations of long standing.

But Rowland, speaking after the dawn of the Electrical Age, no longer represented the majority of his colleagues. Most contemporary physicists and their supporters welcomed the opportunity electricity offered to display the fruits of their labors. Few American physicists had the interest, ability, and opportunity that enabled Anthony and Cross to initiate electrical studies in the 1870s. Yet a decade or two later, virtually every physicist was celebrating the virtues of electricity and its applications. Maxwell, whom Rowland revered, had acclaimed the reversibility of the dynamo "the greatest scientific discovery of the last quarter of a century."[13] Within Rowland's immediate circle, Daniel Coit Gilman, the president of Johns Hopkins, found in electricity a justification for pure research. In an 1882 speech about the role of university research in the progress of civilization, Gilman claimed[14] that electricity had

> wrought greater changes in commerce than the discovery of the passage around the Cape; greater modifications in domestic life than any invention since the days of Gutenberg . . .

Indeed, through the 1880s, Rowland's successors as vice-president of the AAAS physical section either depicted the scientific mysteries of electricity or sang its praises as the gift of physics to the world—or both. In 1887, for example, William Anthony had rebuked Rowland by celebrating the patents taken by American physicists. All but two of the patents were electrical (and those two belonged to Rowland). A. A. Michelson began his 1888 "Plea for Light Waves" with a glowing description of the

> wonderful achievements in the employment of electricity for almost every imaginable purpose. Hardly a problem suggests itself to the fertile mind of the inventor or investigator without suggesting or demanding the application of electricity to its solution.

And in 1889, Henry Carhart, in his "Review of Theories of Electrical Action," characterized for the decade the utility of physics:

> Of the practical applications of electricity it is not necessary to speak. They bear witness of themselves. A million electric lamps nightly make more splendid the lustrous name of Faraday; a million messages daily over land and under sea serve to emphasize the value of Joseph Henry's contribution to modern civilization. . . . The value of the purely scientific work of such men is attested by the resulting well-being, comfort and happiness of mankind.

Ironic turning point

The 1890s brought an ironic twist to the relationship of physics and electrical engineering in the US. By the end of the decade, electrical engineering educators complained that training in a course administered by a university physics department was bound to be inadequate. They questioned the value of abstract investigations in higher physics and argued that the curriculum should include only such physics as was fundamental to engineering.

As the electrical engineers parted company with the physicists, so did the public. The utility of the physicists had never been as clear to the general public as it had been to the educators and physicists themselves. In the schools, electrical engineering attracted new laboratories and substantial funding. The research labs established by General Electric, Westinghouse and Bell Telephone were hailed by the press and public. Physics, by contrast, did not achieve significant academic or public recognition until after World War I, nor become preeminent among the sciences until World War II.

References

1. J. K. Finch, *A History of the School of Engineering, Columbia University*, Columbia U.P., New York (1954), page 68.
2. Background on MIT is in S. C. Prescott, *When MIT was Boston Tech*, Technology Press, Cambridge (1954); K. Wildes, "Electrical Engineering at the Massachusetts Institute of Technology," unpublished manuscript, MIT Institute Archives (1971). Student enrollment figures and course descriptions are in the annual *Catalogs*.
3. W. C. Russel to A. D. White, 8 August 1872, A.D. White Papers (Collection 1/2/2), Cornell University Archives (hereinafter ADW).
4. Anthony to Russel, 30 June 1872, ADW.
5. Anthony to White, September 1873, ADW.
6. Anthony to C. K. Adams, 11 December 1886, Executive Committee Minutes (Collection 2/5/5), Cornell University Archives (hereinafter EC).
7. Anthony to White, 5 August 1872, ADW.
8. Anthony to White, September 1873, ADW.
9. Anthony to Russel, 6 June 1880, ADW.
10. Anthony to Adams, 11 December 1886, EC.
11. Anthony to Board of Trustees, 19 June 1887, EC.
12. The Electrician and Electrical Engineer **3** (April 1884) page 93.
13. Quoted in H. Greer, Popular Science Monthly **24** (December 1883) page 254.
14. D. C. Gilman, *President Gilman's Address at the Euclid Avenue Church*, Fairbanks, Cleveland, Ohio (1883) page 23. □