

## Amalie Emmy Noether (Mathematician)

March 23, 1882 -April 14, 1935



Amalie Emmy Noether has been called by her fellow mathematicians as the most important woman in the history of mathematics. Emmy (she was named Amalie after her mother, but she preferred to use the name Emmy) was a German mathematician who made many important contributions to abstract algebra. Noether's theorem, which explains the connection between symmetries in physical systems and conservation laws, has proven fundamental for mathematical physics. In the book *Symmetry and the Beautiful Universe*, authors Leon M. Lederman and Christopher T. Hill, both physicists, wrote that the Noether's theorem is one of the most important mathematical theorems ever proved in guiding the development of modern physics, possibly on a par with the Pythagorean theorem.

In her later work she developed a completely new theory of ideals in rings. She is also famous for developing ascending chain conditions. This innovation enabled her to treat old problems from a new perspective, such as elimination theory and algebraic varieties.

Emmy Noether's mathematical work has been divided into three epochs. The first one, 1908-1919, was when she made contributions to the theories of algebraic invariants and number fields. In the second epoch, 1920-1926, she developed the theory of ideals in commutative rings into a tool with wide-ranging applications. She made use of the ascending chain condition; objects satisfying it are now named Noetherian in her honor. In the third epoch, 1927-1935, she published works on noncommutative algebras and hypercomplex numbers and united the representation theory of groups with the theory of modules and ideals.

**Her science journey** began when Amalie Emmy Noether was born in Erlangen, Bavaria on March 23, 1882. Emmy was the oldest of the four children of Max Noether and Ida Amalia Kaufmann. Max and Ida both came from wealthy Jewish merchant families. Max was a German mathematician who worked on algebraic geometry and the theory of algebraic functions. He is considered one of the finest mathematicians of the nineteenth century!

Emmy has three younger brothers. Alfred received a doctorate in chemistry from the University of Erlangen in 1909. Fritz studied in Munich and made contributions to applied mathematics. The youngest, Gustav, suffered from chronic illness and died in 1928.



Emmy did not stand out academically when she was a child. She was nearsighted and had a minor lisp. But she was known to be friendly and clever. She was taught to cook and clean, took piano lessons, and studied languages.

She became proficient in French and English. So, at 18 years old, she was supposed to teach French at a girls' school, an acceptable occupation for an unmarried young lady. But she had another idea! She decided she would rather study mathematics at the local university where her father was a professor and her brother was a student. At that time, at the University of Erlangen (now called University of Erlangen-Nuremberg),



women were only allowed to audit classes with the permission of the instructor. She could go to the lectures but couldn't take tests or get a degree. She was one of only two women among 986 students at the university. Emmy was much smarter than everyone else in the class. Her classmates knew it and didn't like it! But they liked the fact that she helped them with their homework and they got credit for all her ideas because, after all, she wasn't officially a student.

She spent the winter of 1903-04 auditing classes at the University of Göttingen, a



world-renowned center of mathematical research. She was taught by mathematicians David Hilbert, Felix Klein, and Hermann Minkowski and astronomer Karl Schwarzschild, all of them famous to this day. In 1904, she returned to the University of Erlangen, as by then women were allowed to be full

students. She received her Ph.D. in Mathematics from the University of Erlangen in 1907, with a dissertation on algebraic invariants. Her thesis adviser Paul Gordan supervised her dissertation *Über die Bildung des Formensystems der ternären biquadratischen Form* (*On Complete Systems of Invariants for Ternary Biquadratic Forms*). She graduated with the highest honor, *summa cum laude*.

She then encountered another obstacle. Women were not allowed to teach at universities. She decided to work without pay, as an assistant to her father Max at the Mathematical Institute of the University of Erlangen. But just like when she was a student, other mathematicians took credit for her work because they knew they could get away with it. If Emmy complained, she could get kicked out of the university since she was not supposed to be there.

In 1915, David Hilbert and Felix Klein invited Emmy to return to the University of Göttingen and use her knowledge of invariants to help explore the mathematics behind Albert Einstein's recently published theory of general relativity.

When the mathematicians tried to write an equation for conservation of energy within the framework set out by Einstein's theory, the results never made sense. So that's why Hilbert invited his brilliant former student to help work on the puzzle. Emmy's expertise was in the field of algebra called "invariance". It dealt with sets of mathematical objects that remain unchanged when transformations (manipulations that change an object's position in space or time) are applied to them. Emmy applied her knowledge of invariant algebra to the general theory of relativity. In doing so, she realized that general relativity caused the laws of conservation to behave differently than expected. That was because the geometry of space and time also behaved differently where relativity operated at such large scales. Emmy proved that, in fact, the energy conservation laws hold when relativity's effects were properly framed and accounted for. Emmy's insights solved the problem that had kept Einstein from announcing his theory to the world. Einstein and his theory of relativity became famous but not Emmy Noether. She stayed at the university and gave lectures under Hilbert's name because some faculty members objected to a woman teaching at the university.

In 1918, Emmy discovered that if the Lagrangian (a quantity that characterizes a physical system) does not change when the coordinate system changes, then there is a quantity that is conserved. In other words, what are known as the "symmetries" of a physical system are closely related to its conservation laws. Her discovery is known as Noether's theorem and has proven to be a fundamental result in theoretical physics.

Thus, Noether's theorem transformed how physicists understand the universe by proving a direct mathematical link between symmetries in nature and conservation laws. Here are some examples:

**Symmetry in Time:** Because the laws of physics do not change over time, energy is conserved

**Symmetry in Space:** Because the law of physics is the same no matter where you are, momentum is conserved

**Symmetry in Rotation:** Because physics works the same at any angle, angular momentum is conserved

In 1919, the University of Göttingen allowed Emmy to proceed with her habilitation (eligibility for tenure). She successfully delivered her habilitation lecture in June and became a *privatdozent*, an academic title in German-speaking countries (i.e. Germany, Austria, and Switzerland) given to scholars who have earned their doctorate and completed a habilitation. The title grants them the right to independently teach and examine university students, but the position is usually an unpaid position.

In 1922, Otto Boelitz, the Prussian Minister for Science, Art, and Public Education conferred on Emmy the title of *nicht beamteter ausserordentlicher Professor* (an untenured professor with limited internal administrative rights and functions). This was an unpaid “extraordinary” professorship, not the higher “ordinary” professorship, which was a civil-service position. It recognized the importance of her work but still had no salary. A year later, she was appointed to the special position of *Lehrbeauftragte für Algebra* (*Lecturer for Algebra*) and was finally given a salary.

From 1920 to 1926, she investigated the general theory of ideals (special subsets of rings) for which her residual theorem is an important part. From 1927, Emmy concentrated on noncommutative algebras (algebras in which the results of an operation such as multiplication depend on the order of the arguments it is applied to), their linear transformations, and their applications to commutative number fields. She built up the theory of noncommutative algebras in a newly unified and purely conceptual way.

In 1928-1929, Emmy accepted an invitation to Moscow State University where she continued working with Pavel Alexandrov, a Soviet mathematician. She worked on her research and taught classes in abstract algebra and algebraic geometry. After she left Germany in 1933, Alexandrov tried to help her gain a chair at Moscow State University through the Soviet Education Ministry. This effort was unsuccessful and she eventually went to the United States.

Emmy also helped edit the *Mathematische Annalen*, a German mathematical research journal founded in 1868 by Alfred Clebsch and Carl Neumann. From 1930 to 1933, she was the center of the strongest mathematical activity at the University of Göttingen. The extent and significance of her work cannot be accurately judged from her papers. Much of her work appeared in the publications of students and colleagues.

MATHEMATISCHE ANNALEN

HERAUSGEGEBEN

VON

A. CLEBSCH UND C. NEUMANN,  
PROFESSOR IN GÖTTINGEN, PROFESSOR IN LEIPZIG.

I. Band. 1. Heft.



LEIPZIG,  
DRUCK UND VERLAG VON B. G. TEUBNER.  
1869.

In 1932, Emmy Noether and Emil Artin received the Ackermann-Teubner Memorial Award for their contributions to mathematics. The prize included a monetary award of 500 Reichsmarks; the Reichsmark was the currency of Germany at the time. It was a long-overdue recognition for her work in the field. Her colleagues however expressed frustration at the fact that she was not elected to the Göttingen *Gesellschaft der Wissenschaften* (academy of sciences) and was never promoted to the position of *Ordentlicher Professor* (full professor).

In September 1932, Emmy delivered a plenary address on “Hyper-complex systems in their relations to commutative algebra and to number theory” at the International Congress of Mathematicians in Zurich, Switzerland. The congress was attended by 800 people and is sometimes described as the high point of her career. Her prominent position as a speaker was a recognition of the importance of her contributions to mathematics.

When the Nazis came to power in 1933, Emmy and other Jewish professors were dismissed from the University of Göttingen. Life became increasingly dangerous. Her friends arranged for her to become a visiting professor of mathematics at Bryn Mawr College, a women’s college in Pennsylvania. She was also going to lecture and conduct research at the Institute for Advanced Study in Princeton, New Jersey where Albert Einstein was also a professor.



In April 10, 1935, less than two years after coming to the United States, she underwent surgery to remove a large ovarian cyst; four days later, she died at the age of fifty-three, probably from a postoperative infection. The world lost a brilliant mathematician!

In a tribute to her, Einstein wrote shortly after her death that “Emmy Noether was the most significant creative mathematical genius thus far produced since the higher education of women began.”

## **HER LEGACY**

Emmy Noether will always be remembered for her contributions to abstract algebra. Noether’s theorem, which explains the connection between symmetries in physical systems and conservation laws, has proven fundamental for mathematical physics.

She will be remembered for helping Albert Einstein explain the theory of relativity. Emmy proved that the energy conservation laws hold when relativity’s effects were properly framed and accounted for.

She developed the theory of ideals in commutative rings into a tool with wide-ranging applications. She made use of the ascending chain condition and objects satisfying it are now named Noetherian in her honor.

She published works on noncommutative algebras and hypercomplex numbers and united the representation theory of groups with the theory of modules and ideals.

She will be remembered for her doctoral students who went on to have stellar careers in mathematics, Max Deuring, Hans Fitting, Grete Hermann, Jacob Levitski, Otto Schilling, Chiungtze C. Tsen, Werner Weber, and Ernst Witt.

In 1932, Emmy Noether and Emil Artin received the Ackermann-Teubner Memorial Award for their contributions to mathematics.

The same year she delivered a plenary address at the International Congress of Mathematicians in Zurich, Switzerland.

The Emmy Noether Medal is given by the Society of Engineering Science to a mid-career researcher in the field of engineering sciences for outstanding

contributions in a cross-disciplinary and /or emerging area. The prize comes with a monetary award of \$1500 and the Emmy Noether Medal.

The Emmy Noether Awards Program sponsored by the Brown Foundation gives awards to aspiring female research scientists in any STEM field. The program provides financial support, mentorship, and networking opportunities to help them pursue research-focused STEM careers. The prize includes a monetary award ranging from \$2000 to \$75000.

The Amalie Emmy Noether Fellowship in Applied Mathematics and Scientific Computing at Brookhaven National Laboratory provides an opportunity for recent post-doctorate researchers to enhance their capabilities in a unique setting within the Computing and Data Sciences (CDS) Applied Mathematics Group.

The Deutsche Forschungsgemeinschaft (DFG), the German Research Foundation, is the largest research funding organization and central self-governing organization for the sciences and humanities in Germany. In 1997, the DFG Emmy Noether Programme was established to give exceptionally qualified early-career researchers the chance to lead an independent junior research group at a German university.

The Emmy Noether Initiatives is run by the Perimeter Institute in Canada and backed by a group of funders and champions of women in science called the Emmy Noether Circle. The council works collectively with Perimeter Institute to increase the number of women in physics and drive the philanthropic support that will advance women at critical stages of their education and careers at Perimeter and beyond. They are specifically focused on leading the growth of the Emmy Noether Emerging Talent Fund, an endowment devoted to providing support and programming for exceptional students at Perimeter.

The European Physical Society (EPS) established the Emmy Noether Distinction for Women in Physics in February 2013 to enhance the recognition of noteworthy women physicists with a strong connection to Europe through nationality or work.

The Noether Lecture is a distinguished lecture series that honors women who have made fundamental and sustained contributions to the mathematical sciences. The annual lectures were established in 1980 by the Association for Women in Mathematics (AWM) in honor of Emmy Noether. In 2013, it was renamed the



## HER SCIENCE JOURNEY

1882 - Amalie Emmy Noether was born in Erlangen, Bavaria on March 23

1900 - Finished high school and was planning to teach French at a girls' school when she decided to go to the University of Erlangen and audit classes in mathematics

1903-1904 - Audited classes at the University of Gottingen

1907 - Received her Ph.D. in Mathematics with the highest honor

- worked as an assistant to her father at the Mathematics Institute at the University of Erlangen with no pay

1915 - David Hilbert asked her to go back to the University of Gottingen to help solve the problem of Albert Einstein's theory of relativity

1918 - Developed Noether's Theorem

1919 - Became a privatdozent, an academic title in German-speaking countries (Germany, Austria and Switzerland) given to scholars who have earned their doctorate and completed a habilitation. It is usually an unpaid position.

1922 - Became a Lecturer for Algebra and received a salary for the first time

1920-1926 - Investigated the general theory of ideals (special subset of rings)

1927 - Researched concentrated on noncommutative algebras (algebras in which the order in which "numbers" are "multiplied" affects the answers), their linear transformations, and their applications to commutative number fields.

1928-1929 - Taught at Moscow State University

1930-1933 - Edited the *Mathematische Annalen*, a German mathematical research journal founded in 1868 by Alfred Clebsch and Carl Neumann.

1932 - Emmy Noether and Emil Artin received the Ackermann-Teubner Memorial Award for their contributions to mathematics.

- Delivered a plenary address at the International Congress of Mathematicians in Zurich, Switzerland.

1933 - Moved to the US to teach at Bryn Mawr College

1935 - Died at 53 years old after a surgery to remove an ovarian cyst

1980 - The Noether Lecture was established by the Association for Women in Mathematics (AWM)

1982 - The Emmy Noether Gymnasium was founded in Erlangen

1997 - The DFG Emmy Noether Programme was established to give exceptionally qualified early-career researchers the chance to lead an independent junior research group at a German university.

2015 - Google did a doodle on her 133<sup>rd</sup> birthday

- The Amalie Emmy Noether Fellowship in Applied Mathematics and Scientific Computing at Brookhaven National Laboratory was established

2013 - The European Physical Society (EPS) established the Emmy Noether Distinction for Women in Physics in February 2013 to enhance the recognition of noteworthy women physicists with a strong connection to Europe through nationality or work.

2019 - The Perimeter Institute Emmy Noether Initiatives was launched.

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