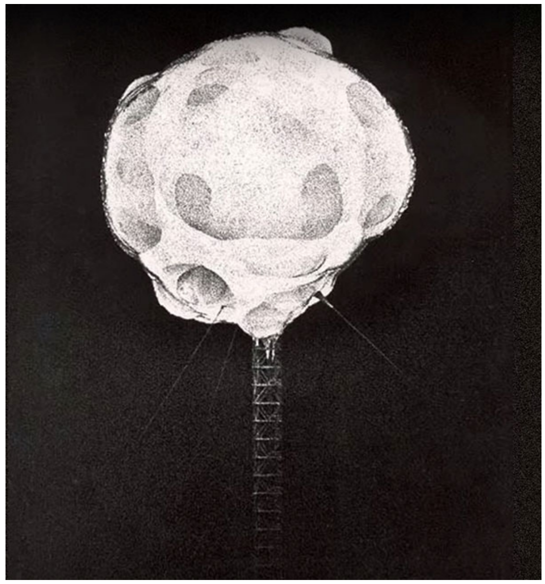

# Cutting the Uncuttable
# Making the Atomic Bomb

by
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Twenty-five-hundred years ago, a Greek philosopher, Democritus, thought about cutting a piece of cheese smaller and smaller. Would it ever become something other than cheese, he wondered? He decided no matter how small the slice, it would always be cheese and from this insight, he concluded that the entire world consisted of tiny indivisible particles. The particles which made up Democritus's world have become the atoms of today and, at the start of the twentieth century, his truth still prevailed and atoms remained indivisible, unchangeable and indestructible; in a word, uncuttable.

## Part 1
## First Steps

### Thomson's Electron (1897)

At Cambridge University, an English physicist, J. J. Thomson, took the first step in dissecting the atom. Inside a vacuum tube, he ran an electric current through a small piece of metal called a cathode and found that the glowing beam it produced bent towards the positive of two electrically-charged plates. The beam in this cathode ray tube had both a mass and a negative charge so, in one experiment, Thompson proved that rather than being a ray[1], the beam was made up of particles. He calculated the mass of these particles as one thousand times smaller than that of a hydrogen atom and, no matter what material he used for the cathode, they had the same charge and mass. Thomson concluded that these particles made up a tiny part of every atom. He named them electrons.

At the time of Thomson's experiment, the scientific community believed everything was made of the uncuttable atom and, since the electron was so much smaller, either there was another form of matter, or the electron was a part of the indivisible atom. If negative electrons were part of the atom, which had no charge, then there must be something else inside with an opposite or positive charge. Thomson proposed the plum pudding model where the positive charge and the negative electron are all mixed together inside the atom. Americans preferred the chocolate chip cookie analogy, where electrons are the chips in the positively-charged atomic cookie dough.

[1] A ray is a wave of pure energy, without charge or mass.

### Becquerel and Uranic Rays (1896)

The year before Thomson discovered the electron, a French physicist, Henri Becquerel, observed that uranium ore gave off rays which exposed a photographic plate. He had no idea what they were, only that they seemed to behave like Roentgen's newly-found x-rays. Becquerel later showed that the rays caused gasses to become charged or ionized[2] and, unlike x-rays, could be bent by magnetic fields. He went on to determine that one of the rays, was identical to the electron, and thus not a ray, but a particle. He also noted changes in the power of the rays over time, but he left it to others to further explore the nature of these mysterious uranic rays.

[2] When a ray or a particle knocks an electron from its orbit, a charge results, and the atom is said to be ionized

### The Sister of Prometheus:<br>Pierre and Marie Curie and radioactivity (1903)

In 1895, Maria Sklodowska, a physics student at the Sorbonne, was in love with Paris, with her studies and with her teacher, Pierre Curie. They were married in July of that year and when a friend offered to buy her a wedding dress, she replied, "If you are going to be kind enough to give me one, please let it be practical and dark so that I can put it on afterwards to go to the laboratory." She wore her wedding dress to work for several years. It was probably contaminated with radium and perhaps glowed with a faint, blue light when she hung it up at night.

When they heard of Becquerel's findings, Pierre and Marie[3] changed the direction of their research from magnetism to this new phenomenon. To determine the strength of the rays, they started using an extremely sensitive device invented by Pierre and his brother, to measure the ionization of the air next to a variety of materials. Most materials showed little or no activity, but, to their surprise, both thorium and uranium showed a high level. It seemed Becquerel's rays arose from more than one substance. When they tested pitchblende, a mineral containing uranium, it showed several times the activity of uranium alone. Marie coined the term, "radioactivity" for these rays and something in the mineral was far more radioactive than uranium. The Curies subjected pitchblende to numerous chemical treatments and eventually isolated two unique radioactive elements, radium and polonium (the latter named for Marie's native Poland). Radium, a rare element, was millions of times more radioactive than uranium. Its purification would prove difficult and prolonged.

Their laboratory at the University of Paris was a long, narrow shed with no heat, no ventilation and a dirt floor. It had been used for dissection, but had been declared unfit for either medical students or cadavers. On any given day, if one peered through the grime-covered widows, one might see Marie stirring a bubbling cauldron with a long iron rod, fumes rising and engulfing her in her dark blue wedding dress. It took them four years and ten tons of pitchblende to purify one tenth of a gram of radium; the purification of polonium took over a decade. These were the happiest days of Marie's life and she often referred to radium as "my child."

The two physicists worked eagerly to discover the properties of their new elements. Radium incessantly gave off heat and glowed in the dark and, over time, polonium altered its radioactive characteristics. Although the transmutation of one atom to another was considered heresy at the time, polonium appeared to change spontaneously into another element. Marie concluded that radioactivity was somehow involved in this alteration. Another curiosity was that the helium present near radioactive elements had a positive charge. Marie thought helium might be related to transmutation but this remained a mystery.

In 1903, Marie received her Ph.D. in physics, the first woman in France to do so, and in the same year, she and Pierre shared the Nobel Prize for physics with Henri Becquerel, but they still did not know the nature of the Professor's strange ray.

J. J. Thomson discovered that the atom was divisible and Pierre and Marie Curie showed that some were changeable; for the first time in two and a half millennia the fundamental concept of matter had been altered. Many years later, at the Paris Opera House during a gala celebration in her honor, Sara Bernhardt referred to Marie Curie as the "sister of Prometheus."

[3] When she married Pierre, she changed her name from Maria to Marie.

## The Rabbit from the Antipodes: Ernest Rutherford and the Birth of Nuclear Physics

Ernest Rutherford was loud, cheerful and opinionated. With his capacious moustache and broad shoulders, one would hardly mistake him for a retiring intellectual. He was a brilliant scientist, an avid experimentalist, an advocate of "joyful and inventive play", the father of nuclear physics and a tolerable rugby player.

Rutherford arrived at the Cavendish laboratory in Cambridge from his native New Zealand in 1895 and worked with Thomson on the experiments which led to the discovery of the electron. Soon he became a true believer in things smaller than the atom. A dogged quest to satisfy his curiosity led a fellow student to note, "We have got here a rabbit from the antipodes, and he's burrowing mighty deep." In 1898, the same year Pierre and Marie Curie invented the word radioactivity, Rutherford received his Ph.D. under Thomson and took a professorship in physics at McGill University in Montreal.

At McGill, he and a colleague, Fredrick Soddy, began working on the problem of radioactive transmutation. Together they proved that radioactive elements change from one to another as Marie Curie had suspected, and that in doing so, they emit two kinds of energy. Alpha rays appeared to be helium atoms stripped of their electrons and beta rays, electrons themselves, but both appeared to be particles, not rays. During this time, Rutherford corresponded with Marie and indeed, many discoveries cannot be wholly attributed to either of them alone.

Radioactive elements progress through a series of alterations from one to another until a stable element is formed; the term used for this is radioactive decay. Rutherford recognized that radium decayed to the element radon with the emission of an alpha particle and that these new high-energy particles could be used to further explore the nature of the atom.

In 1919, Rutherford returned to Cambridge and surrounded himself with brilliant students[4], many of whom referred to him as Papa. He could quickly spot the flaw in a student's floundering experiment and, with his guidance, irrepressible enthusiasm and a supportive word, it would be pursued to completion with a renewed passion.

[4] In all, Rutherford's students would win a total of twelve Nobel Prizes.

### The nucleus (1911)

Rutherford's Cavendish labs, where he worked for most of his career, consisted of sparse surroundings: a cabinet of drawers and open shelves in front of bare brick walls, several sturdy wooden tables and chairs sitting on a tile floor. His favorite kind of apparatus was a bodged contrivance, consisting of glass tubes, dials, switches, bellows, pipes and microscopes, some of it supported on wires hung from ropes strung overhead. To work in the lab, in addition to a mathematician and physicist, you had to be a carpenter, plumber, electrician, glass blower, and machinist. An illuminated sign hung from the ceiling admonishing the occupants to "Talk Softly, Please," but, from time to time, Rutherford violated this commandment by singing Onward Christian Soldiers in a fine baritone as he strolled, dressed in Edwardian tweed, among his students.

One day, Rutherford asked Ernest Marsden and Hans Geiger, to contrive an experiment to fire positively-charged alpha particles at various metals, to see what would happen. They quickly produced a Rutherford-type apparatus, perhaps including string and sealing wax, and used it for many trials. In one, they targeted a thin layer of gold foil. Most of the particles passed through without swerving, but some deflected at an angle and, most interestingly, some bounced directly back towards the source. It took Rutherford and his colleagues two years to explain the gold foil experiment.

The undeflected particles moved through open space, but when one came close to a positively-charged region of an atom in the foil, it was repelled and its path altered. As for the projectiles that bounced back, Rutherford finally concluded that they must have collided with a very tiny, very dense part of the atom, which he deemed the nucleus.

The world soon accepted that the atom consisted of a dense, positively-charged nucleus surrounded by vast amounts of space in which negatively-charged electrons roamed. Thompson's plum pudding — or chocolate chip cookie if you like — model of the atom had died and nuclear physics had been born.