A BRIEF BIOGRAPHY OF FRITZ HABER

Fritz Haber was born on December 9, 1868, in the town of Breslau, Germany. His mother died only a few weeks after his birth, and as a child he was raised alone by his father, Siegfried Haber, a dye merchant, who finally remarried when Haber was seven years old.

Haber was frustrated by what he saw as his father's small view of the world, and he longed to leave Breslau behind. As a student, he was unexceptional; he was interested in many different fields, and grew bored easily with a single pursuit; and he changed universities several times while pursuing a degree in Chemistry. When he graduated, he could not find work, and was forced to return home to work for his father's dye business. Convinced that a cholera epidemic was about to devastate Germany, he begged his father, against the old man's wishes, to invest in massive amounts of chloride of lime, which at that time was the most popular treatment for cholera. When the epidemic failed to materialize, his father had to sell all the excess chloride of lime at very low prices, and his business was nearly ruined. The resulting conflict left father and son more distanced than ever; and Haber left his father's business and tried again to find work in the field of chemistry.

Haber, always a dreamer, spent many years shifting from one unpaid assistant job to the next, unable to find his place. At the age of 24 he converted from Judaism to Protestantism. He may have believed this change would help his academic career (as it often did for German Jews at that time); he also may have been seeking yet another way to distance himself from his father. It wasn't until he was 26, in 1894, that he finally found a paying job, as a laboratory assistant at the University of Karlsruhe.

From these humble beginnings, Haber finally began to achieve some measure of success. He worked 16-20 hour days at Karlsruhe, studying and immersing himself in the newly created field of Physical Chemistry, which combined the traditional disciplines of physics and chemistry. Haber's greatest strengths finally begin to shine through. He had an amazing capacity for learning and hard work; he had a stunning ability to take scientific theories and apply them practically; and he had an extraordinary gift for discussion and debate, being able to dissect a more learned scientist's arguments and pick out holes, logical problems, and also see connections that many others never noticed.

In 1901, when Haber was 33, and his career was rapidly progressing, he wrote a postcard to an old childhood friend, Clara Immerwahr. Clara had just achieved something unprecedented in the history of Germany—after many years of seeking special permissions, getting authorizations from school administrators, and auditing classes, she had become the first woman to get a PhD in Chemistry. Haber visited Clara at a conference in Freiburg, and when he was there, he proposed to her; he wanted to marry her, and he said the two would share a life of science together, working side by side. Clara agreed, they married, and she became pregnant.

Their son, Hermann, was born in 1902. This meant that Clara had to abandon her scientific work, at least for the time being; and at the same time, Haber had finally found the scientific project that would make him one of the greatest chemists in human history. Always in search of the next big idea, Haber set out to solve a problem that had beguiled the greatest chemists on earth for dozens of years. When crops grow in a field, they gradually deplete the amount of nitrogen in the soil. This is why we regularly use fertilizer, which restores that nitrogen. However, at the turn of the century, the only forms of fertilizer that existed were natural, and almost two-thirds of the world's supply was provided by an enormous saltpeter deposit in Chile. However, this saltpeter was rapidly running out, even as world population grew and available farmland shrank; and scientists around the world were desperately warning that within 15-20 years the planet would face a catastrophic famine, enough to devastate the entire world's population.

The problem, then, was how to create synthetic (or man-made) fertilizer, which requires synthesizing ammonia from its elements. The most famous chemists in the world had tried, and failed, to solve this problem; and when Haber, a 35-year-old unknown scientist without any sort of reputation, set out to solve this problem, almost everyone in the scientific community laughed at him. In 1906, when he was 38, he publicly challenged Walther Nernst, perhaps the greatest chemist in Europe, to see who could solve the problem first. Three years later, in 1909, Haber astonished the world by producing the first practical and cost-effective means of creating ammonia, now known as the Haber-Bosch Process. Haber's achievement proves once again that with enough determination, imagination, and hard work, even the most impossible goals can be achieved.

Now one of the most recognized scientists in the world, Haber was allowed to build the largest scientific institute in Europe, the Kaiser Wilhelm Institute, in Berlin in 1911. He made extraordinary amounts of money from his ammonia synthesis; he recruited the most famous scientists in the world to work for him, including the young Albert Einstein, to whom Haber became a sort of big brother; and he traveled in the highest circles of Berlin society. Clara, however, remained at home with Hermann. As Haber's own career took on these gigantic proportions, she felt that no room was made for her own forgotten scientific career, and she gradually became very depressed.

Other than Clara's difficulties, Haber's life could not have been going better when a stunning shock traumatized all of Europe—a Serbian nationalist assassinated the heir to the Austrian throne, and within a month every country in Europe had joined forces against Germany and Austria, as World War I swept across the continent in August 1914. The German military, imagining they would conquer Paris in 39 days, was completely unprepared for modern warfare; the machine gun made their old-fashioned marching tactics completely irrelevant; and within a few months, hundreds of thousands of men were dying from all across Europe. The casualties were staggering; within a month or two, there were more Germans killed in WWI than in every single previous German war, combined. The death rate was too stunning to even comprehend; it seemed that the entire German nation would literally be exterminated within a year or two; and it was at this point that the German military approached Haber about trying to devise an entirely new kind of weapon, one that could clear out the impenetrable enemy trenches that had been built and give the Germans one last shot at a quick, life-saving victory. This was the birth of chemical warfare.

Haber quickly came to the military's aid. He used all his scientific, practical and organizational genius to create the world's first weapon of mass destruction, and on April 22, 1915, the first use of WMDs in human history occurred, on a battlefield at Ypres, Belgium. The attack was a stunning success; but the old-fashioned German military, whose leaders had grave doubts about this "college professor" and his ludicrous-sounding "chlorine gas weapon," did not provide enough troops to take advantage of it. The victory was minor; the enemy quickly began developing its own gases and gas defenses; and Haber, who had unleashed the beast to begin with, committed to seeing it through, and supervising the chemical weapons program until the war's end in 1918.

This was too much for Clara; the night before Haber left for his second attack on the Russian front, Clara committed suicide in their garden. Haber's home was part of the large campus of the Kaiser Wilhelm Institute, and as such, his garden was in a very public area. This, and the timing, has led many people to believe that Clara's suicide was an act of protest. We will never know conclusively; Clara did leave behind a suicide note, but it was quickly destroyed after her death, and its contents have remained a mystery.

After the war's end in 1918, Haber finally received the Nobel Prize for his work on the ammonia synthesis. Many French and English scientists walked out of the awards ceremony to protest this honor being given to "the father of chemical warfare." Haber worked for 15 more years as head of his Institute, but never again achieved the kind of success, fame or infamy that he did for the two works he is remembered for, the ammonia synthesis and the invention of chemical warfare. His great project of the 1920s—to find a way to harvest the microscopic amount of gold in sea water, and thus produce a huge amount of wealth that would pay Germany's war debt—was a spectacular failure. Just as the dreamer Haber had made "bread from the air" with his ammonia synthesis, he hoped to make "gold from the sea" with his new project. But after many years of research and oceanic voyages, it became clear that there was no practical way to extract this gold, and so Haber was denied the sensational follow-up that he thought he could achieve.

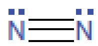
In 1933, Adolf Hitler was appointed Chancellor of Germany, and within a few months he passed a law that required that all non-Aryan and Jewish scientists be dismissed from their laboratories. An exception was made for war heroes; so Haber could have easily stayed. But, disgusted with the Nazi regime, and unwilling to fire his Jewish staff, Haber refused; as a result, he lost the grand scientific institute he had built, and was forced out of Germany, jobless and penniless. Thrown out of the country he so loved and that he had sacrificed everything to help, he wandered Europe in search of a position for several months, before finally dying in a Swiss hotel room in 1934. It was an unbearably tragic end for a man who had loved his country and sacrificed everything for it; as his close friend Albert Einstein later remarked, "it was the tragedy of the German Jew; the tragedy of unrequited love."

SCIENTIFIC OVERVIEW - THE AMMONIA SYNTHESIS

Nitrogen (N) is one of the essential elements of life on earth. Among its many uses, it is critical to agriculture. The fertility of soil directly depends on how much nitrogen there is in it; and every time crops grow in a field, they consume the soil's nitrogen. In the normal cycle of life, plants are consumed by animals, whose waste contains much of the original nitrogen, which is then returned to the soil, for consumption by the next generation of plants. However, in modern agriculture—where crops are planted large-scale and harvested every season—no nitrogen is returned to the soil, and within a few years the field will become barren and incapable of growing new crops.

This is why manure has historically been used as fertilizer, and, along with guano, saltpeter, and other forms of animal deposits, was the only kind of fertilizer available before Fritz Haber. In 1900, there were only two major sources for the entire world—the saltpeter mines in Chile and guano deposits on a series of islands in the

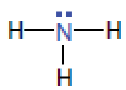
Pacific. This very limited supply was rapidly running out, and without a way to create man-made fertilizer, the world population faced global starvation within the next 15-20 years. So why not just add Nitrogen (N) to the fields directly? The problem is, Nitrogen most commonly occurs in the following form:



N_2 Diatomic Nitrogen

Every nitrogen atom can form three covalent bonds. In "diatomic nitrogen," two nitrogen atoms form a triple bond with each other. This is the most common form of nitrogen, and 80% of the air around us is made up of diatomic nitrogen. However, the bond between the two nitrogen atoms is nearly unbreakable; they cannot pull away from one another and bond with other types of atoms to form proteins, amino acids, or participate in photosynthesis. So you cannot use this type of nitrogen as fertilizer.

To make nitrogen usable as fertilizer, it needs to be converted to ammonia:



NH_3 Ammonia

In "ammonia," the nitrogen atom forms three covalent bonds with three separate hydrogen atoms. In this form, the nitrogen can easily bond with other atoms, and when added to soil, it can be used by crops during photosynthesis. This makes ammonia an ideal basis for creating fertilizer. To make nitrogen usable as fertilizer, it needs to be converted to ammonia:
This conversion process—from diatomic nitrogen to ammonia—is what is known as the "ammonia synthesis."

But what makes this conversion process so difficult? Haber used to boast that in every square yard of air, there is seven tons of nitrogen (in this case, N_2, or diatomic nitrogen). In other words, enormous amounts of nitrogen are all around us. But in order to form ammonia, the following reaction must occur, combining diatomic nitrogen with hydrogen:

$$N_2 + 3H_2 \rightleftarrows 2NH_3 + \text{heat energy}$$

So what Haber needed to do was find the equilibrium point where this reaction would naturally occur. However, the bonds that the two nitrogen atoms have with one another in N_2 are extraordinarily strong. Simply adding hydrogen to the mix does not produce a reaction. In fact, all of the great chemists of Haber's day believed that it would be virtually impossible to create laboratory conditions that would lead to such a reaction.

But Haber, stubborn, brilliant, and audacious, believed otherwise. He knew that there were three basic environmental conditions that could be adjusted in the laboratory to try to cause the reaction:

Heat, which would speed things up, and perhaps lead to a reaction.
Pressure, which would compress the hydrogen and nitrogen, also perhaps leading to a reaction.
Catalysts, or additional elements that could be added to the mix, again to attempt to cause a reaction.

Haber began theorizing that perhaps under intense heat, and extraordinary pressure, and with the right catalyst, the reaction would actually occur. He dreamt of creating a laboratory environment that could heat the gases to 500 degrees centigrade, and subject them to 200 atmospheres of pressure. However, there had never been any sort of device created on earth that could produce these conditions.

At this point, the scientific problem of how to produce the reaction became an engineering problem of how to create a device that could create these extreme conditions of heat and pressure. Again, most of his fellow scientists thought Haber was at best a foolish optimist, and at worst, an insane person. Even a pressure of 10 atmospheres was more than enough to cause a deadly explosion in a laboratory, to say nothing of the almost impossible to imagine 200 atmospheres that Haber wanted to create for his experiment.

But Haber was a dreamer, and always believed that anything was possible, no matter what the obstacles. He shrugged off the difficulties, and began working with a brilliant English scientist named Robert Le Rossignol, who had a specialty for solving engineering problems. Together, after much hard work, and many failures, they successfully created such an apparatus, the first of its kind in the world.
Still, however, the problem was not solved. Even heating and pressuring the gases in this way did not produce the reaction. So Haber began trying a variety of catalysts, a third element that was added to the mix to attempt to coerce the reaction. He went through element after element; some worked, slightly, but ended up producing only a drop or two of ammonia, not nearly enough to be practical. After six years of back-breaking labor, nothing was working; it seemed the other scientists had been right; and Haber, near despair, made a last ditch effort to try a new series of rare, exotic catalysts that he obtained from a German electrical company that made light bulbs. Finally, in 1909, the miracle came. Haber tried adding osmium, a rare and hard-to-find element, as a catalyst. In a stunning moment that changed the scientific world forever, liquid ammonia began dripping rapidly into the receptacle at the end of the device. Haber and Le Rossignol could barely believe their eyes, but it was true—they had solved one of the most difficult problems in scientific history—they had successfully learned how to synthesize ammonia.

SCIENTIFIC OVERVIEW CHEMICAL WARFARE

So how did Haber "invent" chemical warfare? What does that mean? Much like the other achievement for which he will always be remembered, the ammonia synthesis, Haber used his unique scientific and practical genius to solve a problem that everyone—fellow scientists, engineers, and the generals in the military—thought was impossible.

At the beginning of the 20th century, the idea of using gases against human combatants was already something widely discussed and theorized about. (Ancient forms of this sort of warfare did indeed exist—for example, both the ancient Greeks and medieval Chinese had experimented with various forms of "smoke bombs.") In 1912 there was a sensational episode where French police captured an infamous bank robber and his crew by using a primitive form of tear gas. So when World War I began, the idea was certainly in circulation. However, it was one thing to imagine filling a captured house with tear gas to drive out a group of bank robbers. It was entirely another to imagine using gas on a massive scale, across miles of battlefield, in an attempt to poison tens of thousands of soldiers.

There is evidence that, despite international laws preventing the use of "poison gas" in military combat, all of the Great Powers (England, France, Germany, Russia) were actively experimenting with the idea at the beginning of World War I. Faced with a military situation unlike anything anyone had ever imagined—where the machine gun, a newly-invented weapon of unbelievable devastation, could kill hundreds of men in less than a minute, and made any sort of advance by an opposing army impossible—the countries involved in the combat felt they had to begin exploring alternatives.

From most of the evidence, it seems that these early experiments, conducted by top-secret, specialized divisions within each country's military, were for the most part a spectacular failure. This was certainly the case in Germany, where Haber became aware of the military's nascent chemical warfare program several months into the war. The program was an absolute disaster; the scientist in charge, who was appointed to his post because he was a close relative of a German military official, was a complete incompetent; the chemical agents he was using were expensive and ineffective; the artillery shells he used to carry the gases were poorly designed and rarely worked; and most of the German High Command considered the entire program to be an enormous failure. Moreover, after several months in the war, and unable to import or export any materials (since Germany was surrounded by hostile enemies on land, and blockaded by the British Navy at sea), the Germans were running desperately low on every supply imaginable. They could barely provide food and ammunition to their soldiers; and their supply of artillery shells, essential to any chemical weapons attack (because they were needed to project the gas into the enemy trenches), was so low that even the standard artillery regiments had to go regularly without shells for weeks on end.

So Haber was presented with an impossible proposition—the German High Command wanted to create chemical weapons, but had no artillery shells that Haber could use, and had no money or materials to spend on developing chemical agents to create gas with. He had no shells, and no gas, and yet he believed, as he had 10 years ago with the ammonia synthesis, that nothing was impossible, with enough determination, imagination, and hard work.

Once again, Haber's genius lay not only in his scientific abilities, but in his pragmatic approach, his organizational skills, and his highly practical mind. For a chemical agent, he had the breakthrough idea of using chlorine, which is made from salt, and is plentiful, cheap, and very simple to acquire. Anyone who has taken a strong whiff of bleach can attest to its irritating and toxic properties. For the shells, Haber again thought outside the box; why were shells needed? Couldn't there be another way to release the gas? Haber discovered that the German paint industry had thousands and thousands of empty metal canisters that were normally used to store and ship paint. He proposed filling the canisters with liquid chlorine, arranging thousands of them along several miles of the front, angling them so that when they were opened, the liquid chlorine would vaporize, and timing the release in such a way that all were simultaneously opened when a strong wind was blowing toward the enemy trench. Since chlorine was heavier than air, Haber theorized, the gas would form a dense cloud that would hug the earth, roll toward the enemy trenches, and sink into them, leaving nowhere for the enemy soldiers to hide.

As with the ammonia synthesis, Haber's ludicrous-sounding idea turned out to be a stunning success. The gas performed exactly as he had planned, and created a massive hole in the enemy front. But the German generals, who had little faith in his plan, did not commit enough troops to exploit the opening. And unlike the ammonia synthesis, Haber's work was greeted with a universal cry of international condemnation; awful stories of the horrors and suffering of the gassed soldiers filled the newspapers; and Haber became infamous around the world as "the father of chemical warfare."

A QUIZ ON HABER

1. Haber's greatest achievement, the "ammonia synthesis," was:
   a. creating synthetic ammonia, as opposed to the natural kind
   b. causing a chemical reaction that combined nitrogen with hydrogen
   c. forcing ammonia to be liquefied so it could be added to fertilizer
   d. combining ammonia with oxygen to form nitrogen oxide

2. The ammonia synthesis was difficult to produce because:
   a. the bonds formed in diatomic nitrogen are very hard to break
   b. it was hard to create the high pressure and temperatures needed
   c. both a & b are correct
   d. none of the above

3. The three basic variables Haber had to experiment with while creating the ammonia synthesis were:
   a. pressure, heat, and volume
   b. time, heat, and energy
   c. pressure, energy, and volume
   d. pressure, heat, and catalysts

4. Why is fertilizer necessary for modern agriculture?
   a. because modern agriculture relies on greenhouses
   b. because plants need nitrogen to grow
   c. because ammonia is required when there's not much sunlight
   d. because it means plants need to be watered less

5. The gas Haber used in the first chemical weapons attack was:
   a. phosgene   c. chlorine
   b. mustard gas   d. tear gas

6. What were the major obstacles Haber faced while trying to create chemical weapons?
   a. he had no artillery shells and very few chemicals to work with
   b. his laboratory did not have the right equipment
   c. most of his top scientists were already at the front
   d. transporting chemicals to the front was very difficult

7. The Haber process is/was NOT:
   a. used in chemical warfare
   b. still used today
   c. saved millions from starvation in his lifetime
   d. used to create ammonia (e.g., for fertilizer)

Questions for Discussion

Having read about Haber and having seen the film, here are some questions for discussion. Consider not only how you would answer them, but also what the best way to express and support your point of view is.

1. What are the ethical responsibilities of a scientist? Is he or she responsible for the uses of everything he or she creates?

2. Is a factory owner who makes tires that are used on military vehicles just as ethically responsible as a scientist who invents a new weapon?

3. Did Haber make the right decision to help Germany by creating chemical weapons?

4. Haber won the Nobel Prize for his ammonia synthesis, which now feeds 2 billion people. Even if you think Haber's invention of chemical weapons was a great crime against humanity, should he still be recognized for his other work? Should he have won the Nobel Prize?

5. What is the primary role and responsibility of a scientist today? Do you think the situation was different 100 years ago, at the time of World War I?

6. On the basis of the film, do you consider Fritz Haber to be a hero, a villain, at times both, or perhaps neither hero nor villain?

7. Describe some of the pressures that Clara Haber had to deal with.

8. If Clara Haber's suicide was to protest Haber's chemical weapons activity; do you think she made the right choice? Or was her action a senseless loss of life? Or is the answer somewhere in between?

9. How does faith impact Fritz Haber's life? Do you think faith is important to Haber (as presented in the film)? If so, can you describe what it is that Haber has faith in?

10. After having read about Haber, did anything surprise you in the film?

Ethical Debate Questions

Was Haber's decision to create chemical weapons for the Germans the "right" thing to do? Or was it unethical of him to do it? One of the ways we evaluate ethical questions like this is by debating the issue. Several sample arguments are listed below that can be used as starting points for debate.

Since Haber's time, there have been many cases where the relationship between science and the military has been ethically questionable. Consider the following questions:

* Was it unethical for the United States to develop the atomic bomb—a weapon with the ability to destroy the planet—and then use it on a civilian population, twice, to end World War II?
* Is it unethical to use unmanned attack drones in Iraq and Afghanistan, if they reduce deaths among U.S. soldiers, but lead to higher civilian casualties?
* There are often rumors that experimental "truth serums" are used during interrogations. Is this unethical, if these drugs have the potential to permanently damage the prisoners' brains, yet may yield useful information?

Research Projects

Beyond the facts presented in the film and the handouts you've been given, there are many additional topics related to Haber's life and work that are of great interest to the history of science. Below are five projects that ask you to write a report involving additional research.

1. Albert Einstein was one of Haber's closest friends, but took a very different path than Haber in WWI, speaking out against the war and criticizing German nationalism. Write a report that compares Haber to Einstein, and investigates the differences between the two men.
2. Haber's search for gold in the 1920s is a fascinating story. Write a report that describes this project. Why did Haber become involved? How did he first get the idea? Why was he so convinced that it would work? And how did his project advance from his initial idea to its ultimate failure?

3. One of the most interesting facts of European scientific history is that, up until World War II, many of the greatest scientists in Europe were German by birth; and of them, a disproportionately large number were Jewish. Write a report that explores the history of Jewish scientists in Germany and their encounters with anti-Semitism, from 1850 through Hitler's regime in the 1930s.

4. It is often said that chemical weapons were "invented" in WWI by Fritz Haber; but earlier, more primitive examples of chemical weaponry go back to ancient times, from "Greek Fire" to different types of "smoke bombs" used as weaponry by the Chinese. Write a report that traces the history and development of chemical weapons, from ancient times through to WWI.

5. Many chemical compounds created by scientists have multiple uses, many of which diverge from the scientist's original conception. Write a report that follows the historical development of mustard gases from their original use in chemical warfare to their current use to treat cancers (e.g., Bis(2-chloroethyl) methylamine).