The Manhattan Project

Physics in America:

Although Germany, England, and Denmark were the biggest centers of physics research for the first three decades of the 20th century, the United States' physics program expanded rapidly beginning in the 1920s. As industry grew and demand for technically-educated professionals increased, more and more young people received undergraduate and graduate degrees. Philanthropic organizations (especially the Rockefeller and Guggenheim Foundations), a uniquely American phenomenon, funded young students' research and allowed them to visit the famous laboratories of Europe. On the other hand, European physicists increasingly visited the United States on lecture tours, to see the products of American research, or to take positions at one of the country's many universities (European universities typically had small physics departments and few opportunities for new professors). These Europeans were struck by the vitality of the young American program and the cultural differences between the continents: American physicists tended to be more focused on industry and applied science, and were comfortable interacting with the media or commercializing their work; on the other hand, American research teams were less hierarchical and tended to ignore conventional boundaries between disciplines. The philosophical questions introduced by quantum mechanics did not interest Americans, who were willing to accept the new theory's utility and move on.

A key change in the relationship between American and European physics came in early 1933, when Adolf Hitler took power in Germany. Soon afterwards, he expelled Jewish academics from German universities, immediately affecting roughly a quarter of the German theoretical physics community. Over the next several years, many others in Germany and its neighbors resigned their posts, either out of fear or in protest. The British and American communities quickly condemned Hitler's actions and organized to provide the displaced physicists with new university positions in safe countries. Although many (such as Schrödinger and Born) chose to relocate to Great Britain, the majority moved to the United States. Ultimately, Einstein, Fermi, Bethe, Paul Debye, James Franck, Alfred Landé, Emilio Segré, Eugene Wigner, Otto Frisch, Otto Stern, Leo Szilard, Edward Teller, and many others ended up at American universities. Those who chose to stay within the Nazi Reich out of loyalty to their country included Planck, Heisenberg, and Max von Laue. Although the German physics program was not crippled by the migration, the country lost its preeminent position in theoretical physics.

Production of the Bomb:

The story of the American project to develop nuclear weapons in the broader context of World War II is probably well-known to many students, so this summary will give a very general overview of some key details.

Early on, the primary motivation for the program was to develop a bomb before the Nazis could (ironically, serious espionage into the progress of German nuclear research did not begin until 1945, by which time their bomb research had been abandoned). Fearing the danger of a German bomb, the Hungarian-born physicist Leo Szilard drafted a letter to President Roosevelt urging the U.S. to invest its resources into nuclear research. Einstein signed the letter, hoping his fame would lend credibility to the proposal; an earlier meeting between the lesser-known Enrico Fermi and the Navy had come to nothing. Roosevelt approved, but the project stalled until the 1941 attack on Pearl Harbor. The Manhattan Project was put under Army command, with General Leslie Groves directing the project and drawing on the military's massive financial resources. The project eventually consisted of sites in Oak Ridge, Tennessee, where raw uranium was separated into depleted ^{238}U and enriched ^{235}U, which could be used in a fission bomb; Hanford, Washington, where the depleted uranium was converted to plutonium by inducing beta decay inside a nuclear reactor; and Los Alamos, New Mexico, where leading physicists worked on the uranium and plutonium bombs' designs under J. Robert Oppenheimer.

By the early 1940s, the theoretical possibility of a nuclear bomb was well-known among physicists in many countries. Physicists in the Manhattan Project had to deal with technical problems, such as the design of the bomb's triggering mechanism or whether an airplane could handle the bomb's weight. The key issue, which proved insurmountable for the non-American nuclear programs, was separating the uranium isotopes. The three methods eventually used were diffusion (in which uranium hexafluoride gas is pumped through a series of hundreds of mesh barriers which the lighter 235 isotope crosses more quickly), thermal diffusion (consisting of a heated tube placed inside a cooled tube; the uranium gas is placed in the space between, where the lighter isotope diffuses toward the hot pipe and then rises to the top of the chamber), and the calutron (in which uranium is magnetically accelerated in a semicircle, with the 235 isotope moving in a slightly tighter radius and then captured separately). None of these processes were particularly efficient, and they acted as the bottleneck of the project until sufficient enriched uranium was produced by mid-1945.

Community and Secrecy:

Physicists were used to the open, collaborative, largely apolitical atmosphere of the research universities and had trouble adjusting to work at Los Alamos. Beginning in the late 1930s, nuclear physicists had to compromise between sharing their advancements and keeping German competitors in the dark. Szilard and Fermi continued submitting papers to journals in order to establish precedence, but asked that they not be published. Conversely, McMillan and Abelson publically announced their discovery of neptunium, drawing heavy criticism from James Chadwick for potentially compromising the war effort. By the time Groves and the military took control of the Manhattan project, these questions were out of the scientists hands and secrecy was strictly enforced.

Working secretly was especially difficult for Leo Szilard. In addition to the scientists' isolation from the outside world, individual departments within Los Alamos were often cut off from one another. For Szilard, this was a serious impediment to scientific work, which requires cross-pollination between different ideas and thought processes. He tried bringing up his patents on the fission reactor as leverage for greater freedom; Groves, interpreting this as insubordination or espionage, ordered him put under surveillance (these fears of spying, of course, were groundless; Szilard had fled Europe to escape the Nazis). Other Europeans, unused to the American focus on utility and the current need for secrecy, were made uncomfortable by the guarded fence surrounding their workplace. Most were able to get by, reasoning that their restricted freedom was a necessary sacrifice for the war effort.

The community at Los Alamos found ways to adapt to its new environment. A social life of weekend dormitory parties, hiking trips, sports, and theater performances developed as physicists found ways to use their leisure time under security restrictions. The project involved, in some capacity, most of the famous physicists of the day outside Germany, but the great majority were young up-and-coming physicists (probably most famously Richard Feynman). The average age at Los Alamos was 25. Although Oppenheimer was greatly respected as the project's leader who had gathered such a large and diverse community together, even he struggled with the intense and restrictive conditions: he dealt with moral and religious questions which would later become famous, while his wife Kitty turned to heavy drinking.

Physics and Ethics:

There was no universal opinion on the morality of the bomb shared by all physicists. Early in the project, the threat of Germany was sufficient motivation for most to turn to weapons research. After the war ended in Europe in the spring of 1945, many theoreticians began to question the value of their work. Szilard, who had earlier been enthusiastic about the bomb, began arguing during the summer that it should remain secret instead of being used. Ernest Lawrence, born an American citizen, saw no problem with providing his country with tools to support it. Edward Teller, who went on to lay the groundwork for thermonuclear weapons, avoided questions of ethics altogether, arguing that scientists had no business trying to make policy decisions. Oppenheimer's reflections on the destruction made possible by the bomb are famous, and he dealt with guilt for the rest of his life.

One of the most fully-formed positions on the bomb was that of Niels Bohr, who was only marginally involved in the project itself. He foresaw that, inevitably, other countries would develop their own nuclear weapons, leading to the possibility of an arms race. Instead, Bohr urged a cosmopolitan policy of willingly sharing the bomb among different countries. This, he argued, would end war by making war impossible. Nations would be forced to work together in order to avoid mutual destruction, possibly even leading to the end of the nation-state as an entity and the beginning of world government. To the government representatives who heard this plan, the idea of handing over military secrets to enemies was absurd.

Of course, the ultimate decision to use the bomb was made not by scientists but by politicians. By July, 1945, Japan's industrial capacity had been destroyed and the country was considering surrender. However, the U.S. demanded no less than unconditional surrender, which the Japanese refused to accept. This insistence on total surrender has been criticized, but it was motivated by the legacy of World War I: the confusing, conditional surrender of Germany had allowed the country to rearm and begin World War II. President Truman also had to deal with Stalin, who was preparing to declare war on Japan and extend Soviet influence into East Asia as he had in Eastern Europe. The dilemma was thus between ending the war quickly with an invasion at the cost of human lives, or waiting until the Soviets entered the war and gained more bargaining power. Nuclear weapons provided a way out of this problem by shocking Japan into surrender before the Soviet Union could intervene. Soon after the bombing of Hiroshima and Nagasaki, the emperor sidestepped Japan's military leadership and agreed to surrender as long as he kept his imperial sovereignty. As a compromise, the office of emperor was allowed to remain in a purely ceremonial role as Japan transitioned to democracy.

Ultimately, nuclear weapons were not decisive for the war effort: had there been no Manhattan Project, the Allies still would have won. The question of whether Truman's decision was morally justifiable is more philosophical than historical, but there are a few considerations we can raise. Given the requirements of unconditional surrender, excluding the Soviets, and minimizing the loss of life (especially of American lives), using the bomb may have been Truman's only option. It is easy to think of what-if scenarios in which the U.S. negotiated a surrender or cooperated with the Soviet Union against Japan, but determining what would really have happened in those cases is impossible. Finally, it is important to remember that Truman's perspective in 1945 is different from ours today and that considerations or ideas that seem obvious to us may not have seemed possible to him.

Other Nuclear Projects:

The United States was not the only nation to pursue nuclear research during World War II. Great Britain collaborated with many future Los Alamos workers on early research, but was pushed out of development as the military took over and secrecy became essential. Russian physicists were very successful at developing thermonuclear weapons in the early 1950s, but they made little progress during the war. Japan was also far from completing a functional bomb, and whatever progress it achieved was destroyed in American bombing missions.

The most famous non-American nuclear program was that of Nazi Germany, in which Heisenberg served as lead theoretician. For the first two years of the war, the German and American programs made roughly equal progress in nuclear fission. Hitler's many victories throughout Europe convinced German physicists that the war would be quick and that there was no pressure to finish a bomb quickly before the war's end. By early 1942 the situation changed: The U.S. officially entered the war and decided to fully commit its resources to the Manhattan Project. Conversely, the Germans, after failing to decisively defeat the Soviet Union and realizing how difficult the war would become, decided not to waste resources on a project that probably would not see results in time for use during the war; instead, these resources were given to the German rocket program. Fission research continued, but without the necessary funds for large-scale uranium enrichment. Allied bombing also served as an impediment for German scientists that Los Alamos did not have to deal with. Although the threat of Germany motivated much of the Manhattan Project, that threat had largely disappeared before any physicists had arrived at Los Alamos.

Thermonuclear Weapons:

Edward Teller probably was not the first physicist to realize the possibility of building a thermonuclear bomb (also called the Super or the hydrogen bomb), but he is often called the father of the hydrogen bomb. As the Los Alamos lab was being organized in 1943, Hans Bethe was made head of the lab's Theoretical Division rather than Teller. Teller was upset by this, both because he found Bethe's leadership style difficult and because of personal disappointment, leading to longstanding hostility between the two. Oppenheimer resolved that Teller should work on a separate project in order to avoid conflict. While most physicists spent the war working on the uranium and plutonium designs, Teller developed an early model of a hydrogen fusion bomb ignited by a fission explosion. The general consensus during the war was that developing a theoretical Super would be useful, although there were no plans to actually build it.

Work continued after the war, but without the sense of urgency that guided the Manhattan Project. This changed in September, 1949, when the Soviet Union tested its first nuclear bomb. The U.S. was initially unsure how to respond to this. The General Advisory Committee to the Atomic Energy Commission, which included Oppenheimer, Fermi, and several other leading physicists, suggested increasing plutonium production but not pursuing the Super, viewing it as a massively destructive weapon with no practical military use. President Truman ignored this and authorized the bomb's development in early 1950. The largest technical problem this time was the huge amount of mathematical simulation needed to understand the hydrodynamics of the explosion; the first computer, the ENIAC, was designed to run these tests. Teller's original design was recognized as unfeasible and revised by the mathematician Stanislaw Ulam, leading to the successful Teller-Ulam design (the original used the concentric sphere model of the plutonium bomb and exploded too quickly; Ulam's revision allowed the thermonuclear reaction time to develop). Physicists at Los Alamos again designed the Super, which was first successfully tested in November of 1952, with a yield a thousand times that of the original Hiroshima bomb. Within a few years, the Soviet program had developed its own thermonuclear bomb.

Key Ideas:

- Internationalism has appeared before as an important scientific value, inspiring Arthur Eddington to lead the 1919 eclipse expedition in the aftermath of World War I. Similarly, many Manhattan Project scientists justified their work as allowing an eventual state of permanent peace and cooperation between nations. Major wars force scientists to confront these issues and consider their allegiance to their home country. I do not think it is fair either to say that scientists always stick to a belief in internationalism or that they are willing to jettison this virtue as soon as a war starts; rather, scientific values are dynamic entities whose meanings change over time and are interpreted differently by individual scientists.
- Government funding was a key factor to developments in physics before, during, and (as we shall see) after World War II. I think this observation is a strong argument in favor of externalist explanations for the history of science. Exactly why governments or philanthropes chose to give or withhold resources to specific scientific projects can be influenced by a wide range of political, social, economic, or cultural factors. To understand which physicists succeeded in advancing their field, it is necessary to consider the resources available to them; to understand their available resources it is necessary to look beyond science entirely into a wider historical context.
- The negative implications of nuclear weapons are obvious and are frequently discussed in relation to the Manhattan Project. However, the bomb's creators were aware of possible positive effects their work could bring beyond ending the war. Bohr's vision of world governance may seem naive, but his predictions of mutually assured destruction were remarkably far-sighted. Nuclear deterrence is an accepted concept in international relations theory, helping to explain why the U.S. never went to war against the Soviet Union or India against Pakistan.
- The story of European scientists fleeing persecution and joining the American war effort is deservedly famous and was an important factor in the Manhattan Project's success. However, it is worth remembering why these physicists chose to go to the United States. Years before World War II, and with only a little involvement by Europeans, American physics had grown tremendously and rivaled the leading communities in England and Germany. The migration of physicists to America was not only a cause of America's eventual dominance in the sciences, but also a result of it.
- Frequently, the course of nuclear research was controlled not by physicists but by the American or German militaries. This does not mean that scientists were powerless, however: Oppenheimer succeeded in negotiating with Groves for lower military presence at Los Alamos, and, as we have seen, Szilard found ways to resist the military's authority. After the war, the Los Alamos scientists enjoyed new levels of public fame and prestige, which they used to argue for the importance of responsible nuclear energy usage and which gained them advisory positions in government agencies such as the Atomic Energy Commission. If we think of nuclear policy as a conflict between physicists and

the government, both sides had tools they could use to influence the outcome in their favor.

- Like anything involving Nazis, a mythology has developed around the German nuclear project. Questions of the morality of the leading scientists are difficult to answer: for the most part, their motivations were the same as Allied scientists (patriotism and a desire to finish a bomb before the other side). However, the question of whether Heisenberg sabotaged the project through miscalculation is misplaced. Whatever Heisenberg's actions or motivations were, the fate of the German bomb was decided by a lack of government support rather than physicists' decisions.

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