Big Science

The Roots of Big Science:

"Big Science" is a term used to describe trends toward larger-scale research in the natural sciences since the 1940s. During this period, budgets, research teams, machinery, and facilities grew to unprecedented sizes, often requiring cooperation between different institutions or nations. The most visible symbols of Big Science are particle accelerators, some of which are among the most expensive machines ever built, but all areas of physics (as well as space travel, astronomy, biology, etc.) experienced growth. Beyond the changes in scale, Big Science qualitatively transformed physics in important ways. The need for massive funding changed the relationship between physicists, the government, and the military, while the growing size of research teams and administrative structures changed what it meant to do physics on a day-to-day basis.

While Big Science is often associated with post-World War II trends in American government and military policy, traces of it can be seen in the 1930s, especially at Ernest Lawrence's laboratory at Berkeley. Lawrence was an aggressive and charismatic leader who ran a thriving research center in spite of the Great Depression. In order to create increasingly large cyclotrons, Lawrence had to mobilize large sums of money and workers to operate the machinery. He convinced the president and financial supporters of the University of California of the importance of his work, giving him access to state funding and private philanthropy (almost none of his money came from the federal government). Students, postdocs, and Works Progress Administration workers (displaced workers receiving aid under Roosevelt's New Deal) provided a practically unpaid labor pool. Lawrence's use of these resources allowed him to achieve projects on a much larger scale than his contemporaries and gave Berkeley a head start in particle accelerator research.

Lawrence is not just a useful archetype to think about early Big Science; his influence is concrete and traceable. Those who worked in his lab learned his successful leadership style and were able to bring it to other laboratories. Almost all early particle accelerators were constructed under the leadership of physicists from Berkeley. Many of the most important laboratories' directors, such as Wolfgang Panofsky at Stanford or Robert Wilson at Fermilab, worked under Lawrence. In the mid-1980s, the new Jefferson Laboratory struggled to navigate politics and funding until a new director (and Lawrence Lab alum), Hermann Grunder, took over. One of the necessary ingredients of Big Science, mobilization of resources that physicists normally do not have to deal with, was provided in the style of Ernest Lawrence's leadership.

The Post-War Boom:

After World War II, federal funding for physics increased by a factor of twenty over fifteen years. The great majority of this was military funding from the Department of Defense or the Atomic Energy Commission (technically a civilian organization but practically oriented toward the military). The success of radar and nuclear weapons during the war convinced the American government that scientific research, even into seemingly theoretical or esoteric subjects, was key for national defense, and that investments today would pay off tomorrow. The

Korean War beginning in 1950 led to another spending boom. In 1957, just when a recession seemed to threaten funding, the Soviet Union launched Sputnik; the U.S. responded by creating NASA and continued support for particle accelerators. The 1950s and early 1960s were a time of seemingly-unlimited funding and optimism among physicists, who enjoyed popular support and prestige. The U.S. spent about six times as much money per physicist as it did per chemist.

The early important sites of particle accelerator research were Brookhaven in Long Island, which built the 3 GeV Cosmotron in 1953 and the 30 GeV Alternating Gradient Synchrotron in 1960, and Berkeley, which dominated early cyclotron research and completed the 6.2 GeV Bevatron in 1954. Helped by the Sputnik boom, the Stanford Linear Accelerator Center (SLAC) was operational by 1966 and is still the world's largest linear accelerator. Despite its success, SLAC faced opposition from Congressional representatives who questioned its practical use, foreshadowing later trends in funding. The United States was unquestionably the leader in particle accelerators for two decades after World War II, but progress was made elsewhere. CERN (Conseil Européen pour la Recherche Nucléaire) was founded in 1954 as part of a broader movement toward European cooperation, particularly in order to rehabilitate German physicists back into the community after their long separation. Japan had made important progress in the 1930s, building the first non-American cyclotron, but the war's aftermath prevented the country from undertaking large-scale research for many years. The Soviet Union built successful accelerators, but generally did not match American progress.

Although physicists benefitted from this military spending, the source of their money understandably made many uncomfortable. Some objected to the politics of military support, while others simply wanted their independence back. Whether the military influenced the direction of physics research in this period is controversial and not entirely clear, but it is worth mentioning that important innovations such as atomic clocks and the laser have military applications and were funded in part by the military. Beginning in the mid-1960s, opposition to the Vietnam War increased criticism of the physics-military connection both within and outside of the scientific community. The connection effectively ended in 1969, when Congress passed the Mansfield Amendment restricting military funding to projects that are directly related to military applications. From then on, funding was no longer limitless and physicists' reputations were called into question by anti-war and anti-science movements.

Physics since the 1970s:

In this new environment, proposals had to compete for a limited pool of federal money. Although the National Science Foundation (NSF) had existed since 1950, it only took an important role in funding research beginning in the 1970s. Rather than university-controlled laboratories, which restricted access to outsiders, the government shifted toward more economical independent national laboratories. Planning for a "truly national laboratory" in the late 1960s resulted in the creation of Fermilab outside of Chicago, which in 1985 first produced a 1 TeV beam. Illinois was chosen as a location among many competitors due to its central location and, supposedly, in return for its Senator's support of President Johnson's civil rights legislation (although this rumor is unsubstantiated). This process of locations competing for federal funding was repeated with JLab and the planned Superconducting Super Collider (SSC).

The 1980s saw a brief increase in funding under the Reagan administration, which supported high-tech military applications such as the Strategic Defense Initiative (also called Star Wars). Reagan approved a plan to build the largest accelerator in the world, at 20 TeV and roughly $6 billion, and reclaim America's place as leader in high-energy physics from CERN. The SSC, planned to be built outside Dallas, was one of the most controversial physics projects in recent history. Criticism came from physicists, who resented the preferential treatment of high-energy physics in federal funding or viewed the massively expensive project as an abuse of taxpayers' trust. Criticism from Congress increased in the early 1990s, as costs increased and mismanagement was revealed; after the Cold War ended in 1991, physics research seemed less important to national defense. The project was finally cancelled in 1993.

This period also saw an increasing role for non-American particle accelerators. Japan established its own national laboratory, KEK (Ko Energy Butsurigaku Kenkyusho), in 1971, and has become an important center in high-energy research. By some measurements, CERN overtook the U.S. in particle accelerator research in the 1980s, publishing the majority of experimental high-energy papers and receiving more citations per paper. In 2008, CERN's Large Hadron Collider overtook Fermilab's Tevatron as the most powerful accelerator in the world, at an initial energy of 4 TeV and upgrades planned. Other major accelerators have been built in Vancouver, Novosibirsk, and Beijing.

Challenges of Big Science:

Historically, not all physicists have been satisfied with these new directions in scale and organization after World War II. Some from the older generation missed the days of small projects and thought that younger physicists lacked opportunities to show creativity or personal initiative when working among dozens of other researchers; loyalty and cooperation may become personality traits favored above individualism or intellectual freedom. Public attention typically focuses on the newest and biggest machines, rather than the physicists running them, calling into question whether physicists actually play the central role in physics anymore. Especially during the period of military support, Big Science has been criticized for compromising the independence of physics; on the other hand, given the huge scale and cost of modern accelerators, it can be difficult to imagine how particle physics could continue without government funding.

Regardless of how they feel about it, Big Science has presented new challenges and forced physicists to do their work differently. With only a handful of powerful accelerators, deciding which experiments should have access to valuable beam time is contentious; in addition to the merit of a proposal, laboratories have to weigh their cost, duration, and perhaps the established reputation of the researcher. With only limited opportunities to perform experiments, physicists have made efforts to get as much data as possible out of a single experimental trial; it is not unusual for analysis to continue for years after the data were obtained. The long time spans of experimentation and analysis can conflict with the established rhythm of the academic world: it is difficult to write a thesis on a tight schedule based on an experiment that lasts for years. As negotiating with governments and administrators for funding has become more important, physicists have had to split time between actually doing science and more mundane tasks. In large teams, attributing authorship for individual contributions is difficult. This problem only becomes more pronounced as accelerators and team sizes get bigger. In May 2015, a combined paper from the CMS and ATLAS teams at CERN set the record with over 5,000 authors; their names and institutions filled 24 out of the paper's 33 pages.

Key Ideas:

- Dissatisfaction with Big Science raises the question of whether it is possible, at this point, to change the system and remove constraints on the physics community. The argument against change is that Big Science is inevitable: it is impossible to return to a small-scale model of experimentation because new advances in particle physics require such large concentrations of energy. This is true, but it is important to be precise here: even if the scaling up of high-energy physics was inevitable, the specific configuration of the field that we call “Big Science” was not. The particular relationships between science, government, and military, as well as the relationships between individual physicists, have changed over time and will likely continue to change in the future. Focusing on inevitability shifts our attention away from this fluidity and locks us into a particular understanding of how physics is done.

- After World War II, the laboratory director emerged as an important position with specific responsibilities. The director must act as a mediator between the physics community and sources of funding. As time went on and this mediation became more demanding, their job became more specialized and further removed from actual lab work. Ernest Lawrence spent considerable time actually working with his cyclotrons, but lab directors in the 1970s or 1980s had a more administrative rather than experimental role.
- International values and national pride continue to be important conflicting themes throughout the 20th century. Since World War II, physicists from different countries (with the exception of the Soviet Union) have been happy to work together and share results. The animosity between former enemies in the aftermath of World War I has not been repeated. However, many physicists bring up national or local pride in justifying their projects, as each laboratory wants to be the first to make important discoveries. Funding for the SSC was justified as being necessary to keep the U.S. at the forefront of particle physics research. It seems unlikely that excessive nationalism will hinder research any time in the near future, but an undercurrent of competition between countries can be seen.
- Discussions of Big Science often focus on the largest and most expensive facilities that break records or discover new particles, but (maybe paradoxically) small- and medium-scale projects have also played an important role. An interesting example of this occurred at Berkeley in the late 1960s. Many physicists there were disappointed in the decision to build the new national lab in Illinois rather than California, as the famous Bevatron would now become obsolete. Instead of that happening, the Bevatron was physically connected to another machine, SuperHILAC (a heavy ion accelerator), and renamed Bevalac. This combination paved the way for a new area of research, relativistic heavy ion acceleration, at only a moderate price. The same sort of research is done today at Brookhaven’s Relativistic Heavy Ion Collider (RHIC), completed in 2000. Even into the 1970s, it was possible to make advances in particle physics without spending billions of dollars.
- Funding for a new facility or experiment can be refused for many reasons. The decision not to provide funding may come from other physicists, who may judge the project to be scientifically unimportant or simply too expensive, or from non-scientists, who may or may not be educated about the physics they are judging. Being able to understand these reasons and play off them is an important skill for physicists seeking support. An example of the bargaining that accompanies government funding can be found in SLAC’s planning in the early 1960s. Stanford’s Professor Panofsky wanted the facility to be under the university’s control, giving him greater freedom and control over research. The AEC threatened to cut off funding unless SLAC was made a national laboratory with access to non-Stanford physicists and control given to a national committee. As an eventual compromise, SLAC was made a national laboratory operated by Stanford, with Panofsky as its first director.

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