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Historical Articles

The Revolution in Science in America, 1900-1950

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Abstract. The US lagged behind the European powers, Germany, Britain and France, in scientific research and development at the beginning of the 20th century. Why this occurred and how Germany and Britain supported their flourishing scientific research cultures are discussed. The first serious expansion in basic scientific research in the US occurred with the influx of European Jewish scientists fleeing Nazism in the 1930's. They specifically brought with them knowledge of atomic physics. The influence of Vannevar Bush, who was Director of the Office of Scientific Research and Development during World War Two proved crucial for the expansion of civilian research and development after the War, supported by the Federal Government. Also after the War, Operation Paperclip brought German scientists to the US and they had significant influence on developments in aeronautics, rocketry and space exploration.

Keywords: History of science, American science, European science, Nobel prizes, Basic research.

1. INTRODUCTION

Americans are used to thinking of their country as the greatest in the world, both in terms of economic clout and military strength. But few know how it got that way. The fact is that the US became the greatest industrial power, out-performing the UK, its parent country, in industrial output (measured as GDP per capita, to correct for different sized populations) around 1890,¹ and has been estimated to have out-produced all of Europe around 1917, during World War One.²

But in military terms the US had no “regular” Army as generally understood until 1913, when Secretary of War Henry L. Stimson organized one, in the form of four divisions assigned to protect each geographical region of the USA.³ At this time, the UK had a large military force both fighting in and occupying colonies throughout the world. For example, at the Battle of Waterloo in 1813, the British Army, consisting of regular and conscripted forces, numbered around 250,000 men.

But, at least until World War One, and more generally until World War Two, the US was still a secondary power, especially in scientific terms. Most of the great discoveries and basic research that revolutionized Western soci-

ety were made in Europe, in the UK, Germany and France. But eventually the US out-stripped its European rivals in science too. How this happened is a unique and intriguing story.

The first organized attempt to improve US scientific standing was made in 1903 with the formation of the Carnegie Institute of Washington (CIW), founded by Andrew Carnegie, the Scottish immigrant steel magnate.⁴ He specifically envisaged that the CIW would engage in basic research (without specific applications) in all areas of science. But, over time, the CIW's impact was limited.

The next great attempt to expand American science was made during and after World War Two by Vannevar Bush, an extraordinary intellect, who envisaged an early version of the internet, and who was appointed Adviser for Science and Development by President Roosevelt.⁵ His influence caused a revolution in how science was thought of in America, both by the Government and its people.

Most people would be shocked to discover that the US became the great scientific and technological power it is today by ironically exploiting two groups of Germans, first German (and other European) Jewish émigré scientists before World War Two and then German scientists, particularly German rocket and aeronautical engineers, after World War Two.

I endeavor to tell the story of how America became the world's scientific superpower through these developments in science and technology.

2. AMERICA LAGS BEHIND EUROPE IN SCIENCE AT THE BEGINNING OF THE 20TH CENTURY

It was the end of one century and the beginning of another. At City Hall in New York City, electric lights formed giant letters that spelled out "Welcome 20th Century." Thousands of smaller lights studded the exterior of the building, forming delicate strands of red, white and blue. Thousands of US flags hung everywhere, and the entire city was ablaze with lights. If anything could be gauged from this display it was that electricity that had only recently been invented, was here to stay.⁶

As the hands of the big clock on City Hall reached midnight, all the lights suddenly went out. The City was plunged into darkness. It was a moment's silence that signified the ending of the old century, and when the lights returned, it was the signal that the new century had begun. The crowds began to sing again, bells pealed, and fireworks exploded in the sky. It was the beginning of a new century, 1900 had begun. No-one could have

imagined what incredible and amazing discoveries lay ahead that would revolutionize society and everyone's life.

Already, the telegraph that had been invented by Samuel Morse in 1844 had revolutionized long-distance communication. Thomas Edison invented an improved carbon telephone transmitter for telephones in 1877 and the phonograph in 1878. But, it was the development of the first successful light bulb in 1879 that ensured he would be famous.⁷ In search of a way to light up the city he formed the Edison electric light company in NY City and he said "We will make electricity so cheap that only the rich will burn candles."⁸ To do this he invested in what became known as Direct Current (DC) electricity, ignoring the invention of one of his assistants, Nicola Tesla, an immigrant from Croatia, of Alternating Current (AC), a decision he would later regret. The competition between DC and AC is a well-known story,⁹ but AC was found to be by far the best for transmission over long distances and the less dangerous, and when it was chosen to light the Pan-American Exposition in Chicago in 1895,¹⁰ the stage was set for the electrification of America and the world. The future looked bright.

But, notwithstanding these developments pioneered by Edison and a few other inventors, there was a problem in America that few people foresaw. As scientific developments proceeded at a rapid pace in the early years of the 20th century, the US fell behind. Notwithstanding the development of heavy industry, including steel production and extensive railway systems, there was no organized attempt to foster basic research in America.

By contrast, in Europe, Germany and the UK had active and already traditional frameworks of fostering basic research at many famous universities and industrial laboratories. One can see from the ratio of Nobel Prizes that America lagged behind the European nations.¹¹ Nobel Prizes for such important work in physics as the discovery of radioactivity, the nature of the electron and the atom, in chemistry the development of dyes and drugs, in physiology the understanding of hemoglobin and the function of proteins and enzymes. In all these areas the research level and competition were much more intense in Europe than in America at that time (Figure 1).¹²

Here is a partial list of some early German Nobel Prize winners: In Physics; Roentgen (1901), Lenard (1905), von Laue (1914), Planck (1918), Stark (1919), Einstein (1921), Hertz (1925), Franck (1925), Heisenberg (1932). In Chemistry; Fischer (1902), von Baeyer (1905), Buchner (1907), Ostwald (1909), Wallach (1910), Willstätter (1915), Nernst (1920), Wieland (1927), Fischer

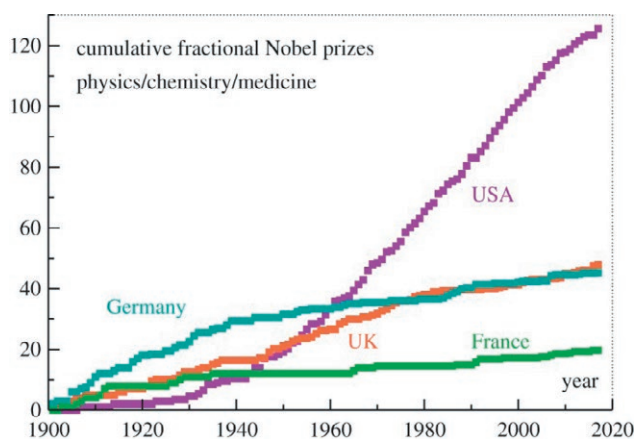


Figure 1. The cumulative number of physics, chemistry and medicine Nobel prizes per country. Prizes are attributed to the respective country according to the nationality of the recipients at the time of the announcement, with prizes obtained by more than one recipient accordingly divided. Note that the US population increased from 76 to 327 million during 1901–2017.¹²

(1930), Bosch (1931). These names are of the highest possible caliber and were responsible for establishing the highest level of these scientific subjects at the time. By comparison during this period the US had the following Nobel Prize winners: Physics; Michelson (German Jewish immigrant, 1907), Millikan (1923), Compton (1927), Davisson (1937), Lawrence (1939); Chemistry, Richards (1914), Langmuir (1932), Urey (1934). Frankly, there is no comparison. The same could be said of comparison of UK and US Nobel Prize winners during the same period 1901-1939.

What is the origin of these differences? In the UK, Government funding of science started in 1675 when the Royal Observatory was established in Greenwich. This was continued in the 19th century with the creation of the British Geological Survey in 1832, and the allocation of funds in 1850 to the Royal Society to award individual grants.¹³

By the First World War in 1915, claims about the poor state of British manufacturing compared to Germany, led to the Department of Scientific and Industrial Research (DSIR) being founded. It was a part of the UK government, staffed by civil servants who distributed grants, operated laboratories, and made policy. Examples included the Radio Research Station, established in Ditton Park in 1924.

In 1918, Richard Haldane produced an official report on the machinery of government that recommended that government departments undertake more research before making policy. It was recommended that they should oversee that specific, policy-minded research was

carried out, governed by autonomous councils free from political pressure.

Following the Haldane Report's recommendations, the Medical Research Council (MRC) was created in 1920 from a previous body called the Medical Research Committee that had been established in 1913 to distribute funds collected under the National Insurance Act of 1911. In contrast to DSIR, the MRC was not a government department, its staff were not civil servants, and its resources were concentrated in a small number of central laboratories and a large number of research units associated with universities and hospitals.¹³ This is still the pattern today.

In Berlin in 1909, Professor Adolf von Harnack, a close adviser to the Kaiser and a member of the Academy of Sciences, wrote a memorandum to Kaiser Wilhelm II in which he outlined a reform of the German science system. He proposed the establishment of independent research institutes conducting specialized basic research. He wrote that the rapid pace of industrialization had demonstrated the need for greater knowledge of basic sciences. Harnack proposed the foundation of a new type of research association for the advancement of science to be known as The Kaiser Wilhelm Society. Harnack's memorandum paved the way for a reorganization and the establishment of research Institutes that still characterize the German science system today.¹⁴

The Kaiser Wilhelm Gesellschaft (KWG) was founded in 1911 for the advancement of science and was formally independent of the German state. Some 30 Research Institutes and testing stations were founded all over Germany in specific areas of science. The KWG had Presidents such as Adolf von Harnack, Fritz Haber, Otto Hahn and Max Planck, and each Institute had its own Scientific Director. Funding was obtained from inside and outside Germany. After WWII the KWG became the Max Planck Gesellschaft.¹⁵

After the First World War the financial situation of the universities and scientific institutions was dire. Their budgets had not been increased since before the War and inflation was rapidly increasing. However, it was precisely in this period following the War that an increase in funding was most needed. The War had been responsible for the interruption of scientific and research activities, young researchers had been called up for military service and research projects had been interrupted. In addition, basic research had been almost completely discontinued in favor of research critical to the war. This situation was further exacerbated by the international isolation of German research, as a result of the Treaty of Versailles, which ascribed sole guilt to Germany for the First World War.



Figure 2. *Left*, Friedrich Schmidt-Ott, President of the Notgemeinschaft from 1920 to 1934; *Middle*, Adolf von Harnack; *Right*, Fritz Haber.

In 1920, leading representatives of science and scholarship in Germany established a working committee, which subsequently adopted the name Notgemeinschaft (“emergency foundation”). Its task was to coordinate joint action and proposals to the parliaments, governments and also potential sponsors in industry, in order to secure the provision of the necessary financial resources to continue basic research. Friedrich Schmidt-Ott, Adolf von Harnack and Fritz Haber played leading roles in this working committee, and also in lobbying the government for funding.^{16, 17}

Friedrich Schmidt-Ott (Figure 2) was elected president of the Notgemeinschaft at the inaugural meeting in 1920. Adolf von Harnack was the President of the Kaiser Wilhelm Society (KWG, later the Max Planck Institutes) founded in 1911. Fritz Haber was director of the Kaiser Wilhelm Institute of Physical Chemistry and Electrochemistry in Dahlem. He was awarded the Nobel Prize for Chemistry in 1919 for the fixation of nitrogen from the air. He and Adolf von Harnack became members of the Executive Committee of the Notgemeinschaft in 1920.

The concerns of the Notgemeinschaft fell on sympathetic ears in government and in society; a decline in the standard of German research compared with other nations was seen as a loss of national honor. In addition, there were concerns about a negative impact on Germany’s future economic development. In an application by the Notgemeinschaft for financial support from the Reich Government in 1920, Adolf von Harnack stressed the importance of science and research for Germany’s overall development:

The vital necessities of the nation include the preservation of the few assets that it still possesses. Among these assets, German science and research occupy a prominent position. They are the most important prerequisite not only for the preservation of education in the nation and for Germany’s technology and industry, but also for Ger-

many’s reputation and its position in the world, on which in turn prestige and credit rely.

Following debates on the allocation of Reich funds to the nascent Notgemeinschaft in the Reichstag,¹⁸ in October 1920 the Reich Ministry of the Interior made 20 million marks available in the 1921 budget year “for the advancement of the goals pursued by the Notgemeinschaft der Deutschen Wissenschaft.” Funding continued in this manner until 1934, when the Committee of the Notgemeinschaft were forced to resign and were replaced by Nazi Party control. Haber who was born Jewish, had converted to Christianity and was a German nationalist, was nevertheless dismissed from all his positions and left Germany and died in poverty in Basle, Switzerland in 1934.

The Notgemeinschaft was the precursor of the Deutsch Forschungsgemeinschaft (DFG) the German Research Foundation after World War Two, that was founded officially in 1951 and became the Federal organization for the support of basic research in the Federal Republic of Germany.

By comparison with the European powers, the fact is that in the US at the beginning of the 20th century there was no Federal Government support for basic research, there were no institutions that were funded to carry out basic research and no Committees existed to foster such research. It is no wonder then that the US fell behind Europe in the early period in the advancement of science and the advantages that could bring for industry and society.

In the US at the turn of the century, many so-called “robber barons” had made huge fortunes in such industries as iron, steel, coal, railways and automobiles. Several of them in later life turned to philanthropy and established Institutes in their name. Thus there is the Frick Institute on the Mall in Washington DC, established by Henry Clay Frick, who made his fortune in steel and railroads, that holds a wonderful art collection. Leland

Stanford in California, who made his fortune in railroads, chose to establish a famous University.

Two of these luminaries chose to establish Institutions that support the concept of basic research, John D. Rockefeller, who made his fortune in oil refining and was reputed to be the wealthiest American, established the Rockefeller Institute in New York City in 1901 for biomedical research.¹⁹ Andrew Carnegie, who had made his fortune in iron and steel production, realized the need for basic research in America and founded the Carnegie Institute of Washington (CIW).²⁰ His initial donation of m\$10 for this purpose was given with the stipulation that only research without any applied objectives should be conducted there. He hoped that this would engender a commitment to basic research throughout America.

Once established in 1903, the CIW engaged in many areas of research, including physics, chemistry, genetics and astronomy. This included Edwin Hubble who revolutionized astronomy in 1929 with his discovery that the universe is expanding, and Barbara McClintock, who won the Nobel Prize in 1983 for her work on genetics in maize. Although the CIW did make important contributions in all these areas it is interesting to note that while the Director of the CIW, Robert S. Woodward, was himself a physicist, the major project in physics that the CIW undertook to pursue was the construction of a wooden-copper boat *The Carnegie*, to sail the seas of the world and establish the earth's magnetic field.^{21, 22} This could not be done obviously in a regular iron ship. But the CIW missed the boat as it were in physics, they chose not to work on the frontline in physics research that was taking place in Europe, where such notables as Rutherford in Britain, Neils Bohr in Denmark, Werner Heisenberg and Albert Einstein in Germany, were grappling with the structure of the atom and its properties. If they had initiated a program of research into the atom, the US might not have had to depend on the immigration of European Jewish scientists in the 1930's to initiate the Manhattan Project to build an A-bomb.

Although the CIW did some notable basic research, its influence was not so great as to bring America in line with its European competitors. During the early part of the 20th Century it was expected that any PhD candidate in science in the US would spend at least some time in post-doctoral studies at one of the great European universities. Also, at the time German was considered the scientific language. Andrew Carnegie's hope that CIW would bring about a revolution in support for basic science in America was not realized at that time.

3. DEVELOPMENT OF MILITARY TECHNOLOGY DURING WWI AND THE INTER-WAR YEARS

It is a well-known truism that warfare results in advances in science and technology that have tremendous consequences. This is certainly true of the main development in military technology that resulted from WWI, namely the tank. Originally ideas of a mobile armored vehicle were conceived by Leonardo da Vinci and H. G. Wells. Wells called them "Land Ironclads" and described their successful use in his story of that name published originally in 1903.²³ But, in reality it took a lot longer to develop them.

At first an American company named Holt of Stockton CA developed caterpillar tractors, that were used to tow heavy equipment around behind the lines of the UK forces in WWI. Their potential as actual fighting vehicles was foreseen by the British who developed a version called the Mark-1 tank that was mainly seen as a means to cross trenches to overcome the stagnant warfare of WWI. Many subsequent versions were produced by many countries and rejected, but tanks were first used effectively by Col. George Patton, in the Battle of Amiens under the command of US General Pershing, that effectively was the last major battle of WWI.²⁴

During the 1920's many improvements were proposed, but mostly rejected by traditionally thinking military commands. However, one innovation that proved significant was that of independent suspension of all wheels of the track proposed by an American transportation engineer named J. Walter Christie in 1928.²⁵ This allowed the tank to move much faster over rough terrain, precisely what a tank was needed to do. This idea too was rejected by US and British Army ordnance officials. But, the Germans, who had been defeated at Amiens by tanks, realized their military significance and took up this idea and incorporated it into their Panzer tanks.

This was one of the main reasons for the defeat of the French and the British Expeditionary Force at Dunkirk at the beginning of World War Two. They were stunned by the speed with which the German tank corps raced ahead and overpowered them. The Russians too took this idea and incorporated it into their tanks and eventually the Americans and British followed suit. Incidentally, one reason that Germany lost World War Two was that although they produced the "best" tank, the famed Tiger tank, they were over-engineered and were so heavy that they had to stop to fire, and Germany produced only 1,350 of these, while the US produced 49,324 Sherman tanks, that were more mobile, more easily repaired and cheaper.²⁶

As well as the development of the tank, parallel advances were made in the areas of automobile technology and in airplanes, from the Wright Brothers first flight in 1903 in North Carolina. WWI catapulted the airplane into prominence, first for reconnaissance of enemy positions and then as fighters facing each other. Detailed analysis of the developments in car engine technology and aeronautics is considered beyond the scope of this work.

4. THE INFLUENCE OF EUROPEAN JEWISH EMIGRES

In the period 1930-39 before World War Two, as the wave of anti-Semitism engulfing Europe developed, there was a positive tsunami of Jewish scientists of German, Austrian, Hungarian and other nationalities emigrating from Europe to the US. Their estimated number by 1944 was 133,000, and they contributed enormously to the development of basic sciences in the US, including increases in patents and expansion of scientific networks.²⁷ Among them was a large proportion of high-level scientists, particularly physicists and chemists, some of whom were helped in various ways by US officials, such as Varian Fry²⁸ and Hiram Bingham III.²⁹ While the majority of Jews were denied visas and prevented from entering the US, due largely to anti-Semitism among State Department officials,³⁰ the cream of the crop of the scientists were facilitated. Among them were the physicists, Albert Einstein from Germany, Leo Szilard from Hungary, Enrico Fermi from Italy, and many others whose names would become synonymous with the leap in American ability in the crucial area for the future war effort of nuclear physics.

Many of these physicists were familiar with the developments being made in nuclear physics in Europe during the period 1900-1930. They knew of the work of Ernest Rutherford in England on the splitting of the atom, of Hans Bethe and Lise Meitner in Germany on the energy produced when splitting the atom, and of Neils Bohr in Denmark on the structure of the atom and his German student Werner Heisenberg, who enunciated the famous "uncertainty principle" and who was later to become the Director of the German nuclear program during World War Two. Each of these individuals contributed significantly to the knowledge and understanding of the atom and of its potential to produce enormous amounts of energy.

However, this culture of scientific achievement in the area of nuclear physics was not present in the US. In fact, the most famous American physicist, Robert Millikan, who had won the Nobel prize in 1923 for meas-

urement of the electron, was quoted as saying in 1929, "There is no likelihood to me that man can ever tap the power of the atom, there is no appreciable energy available to man through atomic disintegration."³¹ However, Ernest Rutherford himself also was skeptical that splitting the atom would result in large amounts of available energy.

Following their arrival in the US, several of these German Jewish emigres played very important roles in atomic research in America. Einstein was accommodated at Princeton, where he played a role in the Institute for Advanced Studies in expanding knowledge of atomic theory. Fermi went to the University of Chicago, where he famously built the first nuclear reactor core Pile-1 under the stadium of the Chicago University and Szilard worked with Fermi.

Szilard authored the famous letter which Einstein sent under his signature to Pres. Roosevelt warning him of the possibility of the development of an atomic bomb with enormous potential.³² This led to the establishment of the Manhattan Project in New Mexico, which was under the scientific direction of Robert Oppenheimer, an American-born Jew.

It is well-known that they did indeed develop the atomic fission bomb and contrary to the original intentions of some of the scientists, two were dropped on the cities of Hiroshima and Nagasaki in order to force the surrender of the Japanese without needing to carry out an invasion of the Japanese Home islands.

What would have happened if these Jewish scientific immigrants had not arrived in the US before World War Two, had they not pursued their research on the atom and had not directly persuaded President Roosevelt to initiate a major and huge commitment to study atomic fission that resulted in the Manhattan project that led to the Atomic Bomb? There would never have been the A-bombs that were dropped on Hiroshima and Nagasaki by order of Pres. Truman and the war would *not* have ended in August 1945 (VJ Day was Aug 15, 1945), but the US would have had to mount an invasion of Japan itself and there would have been an estimated 1 million US casualties.³³

It is not generally known that an attempt at a coup against the Emperor was tried by elements of the Japanese Army in order to prevent him broadcasting his message of surrender to the Japanese people.³⁴ Although some 120,000 people were killed by the bombing of Hiroshima and another 65,000 in Nagasaki, given the amount of resistance encountered in the invasion of Okinawa, and the suicides carried out by large numbers of Japanese, particularly women, it can be estimated that there would have been millions of Japanese casualties

resulting from an invasion of the Home islands. So ironically in effect the dropping of the Atomic bombs saved lives, both American and Japanese, although there is some controversy about whether or not the second bomb on Nagasaki was indeed necessary.

5. VANNEVAR BUSH, AND THE OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT

If any one man could be regarded as instrumental as the initiator and proponent of support for basic research in the USA, that man would be Vannevar Bush (Figure 3). He was born in Everett, Massachusetts, in 1890 and went to Tufts University and MIT. Bush played a role in many engineering developments in circuit design and radio technology that led to the development of the Raytheon Company in 1922 that became a large electronics company and defense contractor. At MIT in 1932 he became Vice-President and Dean of Engineering. In 1938 he was appointed President of the Carnegie Institute of Washington, which brought him in close contact with the Government of the USA. He was an engineer, inventor and science administrator, who from its inception in 1941 and during World War Two was Director of the US Office of Scientific Research and Development, and was the first Science Adviser to a US President, President Roosevelt. Although many scientists made contributions towards the development of scientific research in the USA, Vannevar Bush was pre-eminent among them.⁵

In 1940, prior to the US joining the War, the British revealed to the US that they had made significant strides



Figure 3. Vannevar Bush seated at his desk (Library of Congress).

in developing radar to detect approaching German airplanes. Realizing the significance of this technology Bush arranged for MIT to develop airborne radar that was available by 1941.

Bush's developments in circuit design had enabled him to effectively develop an analog computer. In 1940, Norbert Wiener approached Bush with a proposal to develop an electronic computer. Bush declined to provide funding because he thought it could not be completed before the end of the war. In this he was correct, but nevertheless, Wiener approached the Army and they provided funding to build what would be known as ENIAC, the world's first electronic computer. Bush was considered short-sighted by many, he refused to provide support for social sciences and also refused to support the development of rockets or missiles. For this he was later criticized.

One of the first applications of science to military technology that Bush oversaw was the proximity fuse, that was developed by Merle Tuve and James Van Allen. This was designed to ensure that bombs would explode even if they did not directly hit their target, they only had to be in the proximity of their target. This was not only advantageous because it increased the likelihood of an effective explosion, but also the damage caused by blast was also very significant. When these proximity fuses were used in American ordnance in the first involvement of American forces in North Africa in 1942, Sir Solly Zuckerman, who was to become the British equivalent to Bush, who was an expert in the effects of bombing, discovered that the American bombs were more efficient at taking out German emplacements than the British ones. When he discovered why, he immediately recommended that the British adopt a similar proximity fuse.³⁵

Perhaps Bush's most significant initiative was his role in persuading the US Government to undertake a program to create an atomic bomb that would become the Manhattan Project. Bush met with Pres. Roosevelt in 1941, and following the initiative of the German Jewish émigré nuclear scientists Szilard and Einstein in 1939 and the British program in atomic development, Roosevelt gave his go-ahead for a crash program. The Manhattan Project was to be run by the US army under the direction of Secretary of War Henry Stimson and of Brigadier Gen. Leslie Groves and under the scientific direction of Robert Oppenheimer. He had carried out calculations that estimated that for a Uranium-235 bomb to achieve criticality would require 2.5-5 kg. If we are to believe the evidence of Werner Heisenberg, who was in charge of the German nuclear program, the Germans made mistakes in their calculations and thought that it would require much

more, as portrayed in the historical drama “Copenhagen,” involving Niels Bohr and Heisenberg.³⁶

6. THE AMERICAN REVOLUTION IN SCIENCE AFTER WORLD WAR TWO

After the War, the Office of Scientific Research and Development was no longer needed and was disbanded. But Vannevar Bush realized that there was a great need for a peacetime agency to replace the function of OSRD in promoting science and technology for the national interest. He wrote an essay in 1945 that is considered the most influential paper relating to science and technology every produced in the USA. It was entitled “Science, The Endless Frontier,” that was a Report to Pres. Roosevelt,³⁷ urging the establishment and funding of such a peacetime organization. Note there was 36 years between Vannevar Bush’s Report to Pres. Roosevelt and the similar memorandum of Adolf von Harnack to Kaiser Wilhelm II, a measure of the lag in US understanding of the significance of basic scientific research. The change from President Roosevelt, who died in 1945, to President Truman, resulted in a significant loss of influence for Vannevar Bush. Through many political changes and compromises Bush’s Report finally resulted in Congress establishing the National Science Foundation (NSF) in 1950 that funds basic research in the USA.

One other significant influence that Vannevar Bush exerted on science in the US after World War Two was his concept of large-scale data manipulation needed for the pursuit of science, something that he called Memex. He had thought about this since the 1930’s and he crystallized his ideas in an article entitled “As We May Think,” that was published in *The Atlantic* magazine in 1945. It consisted of a data storage device in the form of microfilm that could be rapidly switched to enable rapid access to different information. This paper was a forerunner of what we call “the information age,” and was extremely influential in the thinking of people who set about using electronic means to develop the mouse, the computer and the internet.³⁸

Apart from their singular influence on the developments in nuclear physics which resulted in the atomic bomb, European Jewish immigrant scientists had a widespread salutary effect on American science. This is attested to by the general increase in scientifically based patents produced in subsequent years following their immigration and the development of a much wider range of research on basic scientific subjects.²⁷

Note that Jews have won 26% of Nobels in physics, 20% in chemistry, 27% in physiology or medicine and

41% in economics. Although Jews are only 0.25% of the world’s population they have won a staggering 24% of all Nobel Prizes in science (physics, chemistry and physiology or medicine). If we take the period 1901-1939 Jews won 15% of German Nobel prizes while being less than 1% of the German population. From 1939 onwards, when there were no longer any Jews in Germany, the number of Nobels won by Germans did not increase significantly for some time (Figure 1), but this is not surprising since Germany had lost the War and was devastated. Similarly after World War Two the increase in number of Nobels in the UK, which had won the War but was similarly devastated, grew only very slowly. But the US experienced a sharp increase in Nobels following World War Two and surpassed the individual European nations after 1960 (Figure 1), as both its population and expenditure on Research and Development significantly increased.

Countries with increased Research and Development expenditures demonstrate higher growth performance with higher levels of GDP per capita than other countries.³⁹⁻⁴¹ This salient fact indicates that apart from the influence of the European émigré scientists and the subsequent influence after World War Two of German scientists transferred to the US, particularly in the area of rockets and aeronautics, it was the decision of the US to expend a large amount of funding on research and development after the War that led to its accumulating wealth in that period.

After World War Two, it was perhaps a shock to the Western allies to find that the Germans had been so far ahead in various areas relating to military technology. For example, in the development of rockets, such as the V2, that could be fired into the stratosphere and then crash into a city far away and cause enormous damage. The Allies had no such weapons. Also, the Germans developed the first functioning jet airplane, the Me 262 (called the Schwalbe or swallow), that was used in combat at the end of the War. It could easily outfly the propeller planes of the Allies, although it was developed in 1942, not enough of them were produced to affect the outcome of the War.

To obtain the secrets of German research on these and other technologies, there was a race between the US and the USSR as the War came to an end to capture and use the expertise of the German scientists. Those who were caught and transferred to the US were, of course, quite happy not to share the fate of the rest of the Nazi apparatus they had served. This US operation was called Operation Paperclip and resulted in ca. 1,600 German scientists and engineers being transferred to the US.⁴² Werner von Braun, the Head of the German rocket

program under the Nazis, whose products, including the V2, that killed tens of thousands of slave laborers in their construction and Londoners as their targets, was never charged with any war crime. Instead, he was appointed Head of the US Army's ballistic missile program and then Head of The National Aeronautics and Space Administration (NASA) space program. The reason was, of course, to try to beat the USSR in the development of rockets and in space exploration. He received the US National Medal of Science in 1975.

The origin of the National Institutes of Health (NIH) can be traced to the Marine Hospital Service started in the late 1790s that provided medical relief to sick and disabled men in the U.S. Navy. By the 1870's a network of Marine Hospitals was developed and Congress allocated funds to investigate the causes of epidemics like cholera and yellow fever. The National Board of Health was also created, making medical research an official government initiative.

In 1887 the Hygienic Laboratory was established at the Marine Hospital in New York for the study of bacteria. In the early 1900s Congress began appropriating funds for the Marine Hospital Service. In 1922, this organization changed its name to Public Health Services and established a Special Cancer Investigations laboratory at Harvard Medical School. In 1930, the Hygienic Laboratory was re-designated as the National Institute of Health by the Ransdell Act, and was given \$750,000 to construct two NIH buildings in Bethesda MD.⁴³

Over the next decades Congress would markedly increase funding of the NIH until today it is in the billions of dollars, and various institutes and centers within the NIH were created for specific research programs. In 1944, the Public Health Service Act was approved, and the National Cancer Institute became a division of NIH. In 1948, the name changed from singular National Institute of Health to plural National Institutes of Health.

The NIH's functions were divided into two, the intramural research program, and the extramural grant program. Each Institute has its own separate intramural and extramural programs designed to advance knowledge and understanding of disease and therapy in each of the major disease categories and to support research through competitive grants at Universities and Medical Schools throughout the USA and the world.

In the period up to the end of World War Two the US relied primarily upon a laissez-faire approach to scientific research and development. In 1950 President Harry S. Truman signed Public Law 507 creating the National Science Foundation (NSF), which provided for a National Science Board of twenty-four part-time members. The NSF began its first full year of operations with



Figure 4. US Federal Government spending on research (in billions of 2017 dollars).⁴⁵

an appropriation from Congress of \$3.5 million, with which 28 research grants were awarded. After the 1957 Soviet Union orbited Sputnik 1, the first ever man-made satellite, national self-appraisal questioned American education, scientific, technical and industrial strength and Congress increased the NSF appropriation for 1958 to \$40 million.⁴⁴

Between them NIH and NSF funding account for most of the biomedical and scientific research carried out in the USA, and constitute the largest commitment of any country around the world to the funding of basic research (Figure 4).⁴⁵ The significant increase in scientific research in the US after World War Two parallels the increase in the number of Nobel Prizes won (Figure 1).

7. AMERICA BECOMES WORLD LEADER IN SCIENCE AND TECHNOLOGY

The tremendous increases in expenditures in support for basic scientific research that occurred in the US after World War Two resulted in a veritable explosion of notable accomplishments. The NIH and NSF that fronted the support for research in the health-related medical sciences and the basic sciences respectively, brought extensive advances in understanding of both the biological and the physical world. These advances in knowledge and understanding also resulted in inventions and applications that have revolutionized our world.

These include the transistor that was developed by William Shockley and his team at Bell Labs in 1947, that triggered the development of electronics; the printed circuit that was developed by the US Army during the War and released for commercial use in 1948, key to miniaturization of electronics; the key development of the computer, both hardware by Steve Jobs and Steve Wozniak and DOS software by Bill Gates; the internet, that was first developed as the ARPANET in California in the 1960's; and then of course there was the smartphone. In biology, advances in genetics resulted mainly from the ability to sequence large segments of DNA,

including the human genome. and this led to the understanding of genetic function.

It is tempting to conclude that all these developments could only have occurred in the US at that time. Clearly the European nations were not only devastated by the War, but also lacked the necessary funds and expertise to continue along the path that could have been projected from before the War. The other victorious Allies, Britain and Russia, were both forced into a long period of recovery. Only the US had the largesse and the industrial potential of exploit the commercial possibilities brought about by this revolution in thinking about science in the US.

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