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Title: Alexander Forbes, Walter Cannon, and Science-Based Literature

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Abstract: The Harvard physiologists Alexander Forbes (1882-1965) and Walter Bradford Cannon (1871-1945) had an enormous impact on the physiology and neuroscience of the twentieth century. In addition to their voluminous scientific output, they also used literature to reflect on the nature of science itself and its social significance. Forbes wrote a novel, *The Radio Gunner*, a literary memoir, *Quest for a Northern Air Route*, and several short stories. Cannon, in addition to several books of popular science, wrote a literary memoir in the last year of his life, *The Way of an Investigator*. The following will provide a brief overview of the life and work of Forbes and Cannon. It will then discuss the way that Forbes used literature to express his views about the changing role of communications technology in the military, and his evolving view of the nervous system itself as a kind of information-processing device. It will go on to discuss the way that Cannon used literature to articulate the horrors he witnessed on the battlefield, as well as to contribute to the philosophy of science, and in particular, to the logic of scientific discovery. Finally, it will consider the historical and philosophical value of deeper investigation of the literary productions of scientists.

Key Words: Walter Cannon; Alexander Forbes; Edgar Adrian; Nerve Physiology; Vacuum Tube

Word Count: 7, 933

Introduction

Walter Cannon (1871 – 1945), one of the most important physiologists of the twentieth century, advised young scientists in the craft of scientific writing: "It is essential that a scientific observer should be able to write a clear and definite report of his aims, his methods, his results, and his conclusions. Flowery language and dramatization are out of place in scientific exposition….The prime requirements are clarity and brevity" (Cannon, 1945, p. 40). At the time, such guidelines were optional; today, they are requisite for publication in any top-tier peer-reviewed journal. Good scientific writing, on the one hand, and "flowery language and dramatization," on the other, have become antithetical.

It is fortunate, however, that Cannon himself, in the last year of his life, chose to violate those strictures, which really pertained to laboratory and theoretical research papers, in crafting his literary memoir, *The Way of an Investigator*. Scholars of science are also fortunate that Cannon's friend and colleague at Harvard's Department of Physiology, the nerve physiologist Alexander Forbes (1882-1965), also opted to express himself in a literary vein. In addition to Forbes' voluminous scientific output, he also wrote a science fiction novel, *The Radio Gunner*, a literary memoir, *Quest for a Northern Air Route*, and several short stories about his outdoor adventures.

The following will provide a brief synopsis of the life and work of Alexander Forbes, and then of Walter Cannon. Then it will discuss Forbes' book, *The Radio Gunner*, followed by a discussion of Cannon's *The Way of an Investigator*. Finally, it will reflect on the value of this excursion for historians and philosophers of science.

Alexander Forbes

Alexander Forbes came from a wealthy and politically powerful Massachusetts family.[1] His father, William Hathaway Forbes, was the first president of the Bell Telephone Company. His mother, Edith Emerson, was the daughter of Ralph Waldo Emerson. His circle of friends and acquaintances included Franklin Roosevelt, and though he was of independent means, his friends and admirers held that Forbes was, "as much at ease in the White House as in an Eskimo hut in Labrador" (Fenn, 1965, p. 130). Forbes attended Harvard College from 1900 to 1905, then continued at Harvard Medical School from 1906 to 1910. In between, he spent a year camping and rafting in Wyoming, partly on the recommendation of a physician in hopes that it would rectify a progressive hearing loss in one ear (which it didn't).

Immediately upon Forbes' graduation, Walter Cannon – then chair of the physiology department – offered him an instructorship in physiology. This he accepted, becoming an assistant professor in 1921 and a full professor in 1936. Forbes and Cannon maintained friendly relations until the latter's death. Due to their somewhat divergent research interests, they only coauthored a single paper; they corresponded extensively, however, about the technical details of instrumentation and on mundane departmental matters such as appointments and salaries. By his death, Forbes had published over 100 scientific papers, a novel, a literary memoir about his wartime experiences, several short stories about his outdoor adventures, and a manual on sailing.

Forbes was a pioneer in the construction and application of physical techniques to the study of the nervous system. Shortly after graduating from Harvard Medical School, he spent a year at the University of Liverpool with the neurophysiologist Charles Sherrington (1857 – 1952) and occasionally visited Keith Lucas (1879 – 1916) at Trinity College, Cambridge. Here he became adept at electrophysiological methods and, upon returning to Harvard, installed one of the first string galvanometers in New England. His

[1] General biographical material is drawn from Davis (1965), Fenn (1969), Frank and Goetzl (1978), Frank (1994), Finger (2004), and Marcum (2006), as well as the Alexander Forbes papers of the Francis A. Countway Library of Medicine at the Harvard Medical School, and published primary sources.

first two major publications came in 1915, in which he and Harvard medical student Alan Gregg (later president of the Rockefeller Foundation) measured the reflex arc in cats.

He expressed his fascination for physical problems of measurement in an opinion piece that appeared in the journal *Science*, in which he deplored the disconnection between physics and physiology and urged greater collaboration between practitioners (Forbes 1920). He realized, as did his friend and colleague, the English nerve physiologist Edgar Douglas Adrian (1889 – 1977) of Trinity College, Cambridge, that physiological education left students ill-prepared to take on some of the most pressing challenges of the field, precisely because those problems required a physical and mathematical acumen foreign to the curriculum. As Adrian remarked in a letter to Forbes dated November 19, 1925, “the amazing thing is that we have to become histologists, micro-dissectors and even psychologists as well as electricians, plumbers, mechanics and photographers” (Alexander Forbes papers, Box 1, Folder 2).

During World War I, Forbes volunteered his services to the Navy in the area of radio engineering. He installed radio detectors in ships as homing devices for guidance in poor weather conditions. This experience also gave him facility in the use of vacuum tubes, an instrument that amplified radio signals. (This important chapter of his life will be discussed again below, because it is crucial for appreciating the complex interrelations between his scientific and literary ambitions.)

Immediately after the war, Forbes became one of the first scientists to develop and implement the idea of applying the vacuum tube to the amplification of nerve impulses. This prepared the ground for one of the milestones of nerve physiology, when Adrian successfully used the vacuum tube to record the electrical activity of a single sensory neuron in 1925. (Forbes almost certainly gave Adrian the idea of using the vacuum tube for amplifying the electrical activity of nerve – see Hodgkin, 1979, p. 24.) For this achievement, Adrian received the Nobel Prize for Physiology or Medicine in 1932, an honor he shared with Charles Sherrington.

Forbes continued work on the foundations of the nerve impulse in the 1920s. In 1922, he solidified his reputation as a major nerve physiologist through an adventurous and exhaustive survey of nerve anatomy and function for the *Physiological Review*. In 1926, he published the results of his work with Harvard colleague Hallowell Davis (1896 – 1992) and others, which effectively resolved an ongoing controversy about whether the action potential continually decreases in velocity when traveling through a narcotized nerve. They established that it does not: the action potential speeds along at uniform velocity through narcotized nerve, though at a reduced speed relative to non-narcotized nerve.

In the 1930s, in a series of publications, Forbes weighed in on the famous "soups vs. sparks" debate on synaptic transmission. He urged a conciliatory position in which both chemical and electrical transmission are operative in central nervous system synapses (Marcum, 2006). During the 1930s, and quite independently of his work on nerves, he helped to develop a novel mapping technique, oblique photogrammetry, which enabled the transformation of oblique aerial photographs of land into planar representations, thus saving geographers an enormous amount of time and resources. In the mid-1930s, he joined an expedition to map the coast of Labrador using this technique; the American Geographic Society honored him with the Charles P. Daly medal for this achievement. Forbes had an unusual capacity for excellence in highly diverse research endeavors.

World War II took him from scientific research again, where, as lieutenant, he worked with a naval crew to discover a new flight path for the safe transportation of fighter jets from Newfoundland to Britain. The problem they wrestled with was that transporting the fighter jets overseas made them vulnerable to German submarine attacks. Forbes made several recommendations for locations for airports. Though the airports were built, the route was never used for transporting fighter jets; the airports found utility as weather stations instead. After the war, he recorded the shock waves from nuclear tests at Bikini Island. After the war, he resumed his post at the department of physiology and published almost twenty additional scientific papers on retinal excitation in reptiles.

Forbes' love of science was matched only by his love of the outdoors and outdoor sports, most particularly sailing, but also mountain climbing and flying, the last of which he only took up in his mid-40s. His biographer Wallace Fenn remarked that Forbes probably would have accomplished more for science if not for his love of adventure (Fenn, 1969, p. 131); Adrian (1965) reached the same conclusion. This is doubtlessly accurate, but Forbes would have contested this way of putting things: for Forbes, science and adventure were not antithetical to one another, but bound together in a deep unity. The narrator of *The Radio Gunner* portrays science itself as a peculiar manifestation of the spirit of adventure, distinguished by its orientation toward the discovery of hidden laws of nature rather than new geographical locales:

> No exploration of new continents, no searching for hidden gold can lure the spirit on with so strong an appeal as the unknown law of Nature awaiting the crucial experiment, planned and prepared for months, and then appearing at last like the light of day when the experiment is done and the measurements construed with the power of reason. (Forbes, 1924, p. 13)

Moreover, through his literary ventures, Forbes was able to fuse his two loves into one – his love of science (with its problems of instrumentation) and his love of outdoor adventure. *The Radio Gunner* is a science fiction adventure that takes place on the rough, open seas and whose protagonist helps to win a major world war through his brilliant use of radio technology – both to communicate coded messages to allies and to locate and sink enemy submarines. His later, autobiographical, book, *Quest for a Northern Air Route*, interweaves technical discussions about mapping and photogrammetry with, as an early manuscript put it, "far-flung travel as fantastic and capricious as the sequences in Alice in Wonderland" (Alexander Forbes papers, Box 49). It would not be an exaggeration to say that his literary ventures acted as a theater for the imagined and simultaneous satisfaction of both passions.

Walter Bradford Cannon

Walter Bradford Cannon was born in rural Prairie du Chien, Wisconsin, the first of five siblings.[2] His formative years were marred by unhappy circumstances. Not long after his birth, his father, Colbert, was kicked by a horse and got a skull fracture. Although his father lived, friends said that he became moody and eccentric. At the age of nine, his mother, Wilma Cannon (née Denio), died of pneumonia shortly after the birth of his youngest sister. Within weeks, the infant girl followed her mother. Thereafter, Colbert Cannon took up odd jobs, moving his children several times and even taking his son out of high school for two years to work in a railroad office.

Despite his unfortunate circumstances, Cannon's rural upbringing contributed both to his aptitude with mechanical devices and his love of nature. In 1901, he married his high school acquaintance, Cornelia James. They spent part of their honeymoon in Glacier National Park, Montana, and, on something of a whim, decided to scale the difficult, 10,000-foot Goat Mountain. As it turned out, they were the first to do so, and the U. S. Geological Survey renamed it "Mt. Cannon" to honor their achievement. Like Forbes, Cannon saw no discontinuity between outdoor adventure and scientific inquiry; the latter represented a kind of reorientation of the spirit of adventure:

> Now that geographical boundaries in our own and in other civilized lands have been determined, the pioneering spirit finds in scientific research enticing vistas for adventure. The twilight zone between what we know and the vast unlimited range of what we do not know presents us with innumerable frontiers. (Cannon, 1945, p. 27)

Cannon began at Harvard College in 1892 and enrolled in medical school in 1896. There he worked under the chairmanship of the famous physiologist, Henry Pickering Bowditch (1840 – 1911), and visualized digestion with the newly discovered roentgen rays (X-

[2] General biographical material is drawn from Dale (1947), Fleming (1984), Benison et al. (1987), and Wolfe et al. (2000), as well as the Walter Bradford Cannon papers of the Francis A. Countway Library of Medicine at the Harvard Medical School, and published primary sources.

rays). But Cannon's interests were not only in research, but pedagogy. In his senior year, he published a proposal in the *Boston Medical and Surgical Journal* urging the utility of case studies in medical education, with their richness and ambivalence, as an alternative to the rote recitation of established facts of physiology.

In 1900, Cannon was offered an instructorship in physiology with the enthusiastic support of Henry Bowditch and William Porter. In a letter to the president of Harvard, Porter described Cannon as "unusually promising" (Benison et al., 1987, p. 71). Cannon did not disappoint them. Upon accepting his post, he resumed intensive research on the muscular mechanism of digestion, using the X-ray technology to great effect by creating what later became known as the "bismuth meal." This was a meal mixed with heavy meals that, when the rays were set upon them, outlined clearly the structure of the stomach. In 1906 he succeeded Bowditch as the Chair of Physiology.[3]

His first book, *The Mechanical Factors of Digestion* of 1911, summarized his work on digestion and brought him immediate fame in medical circles. It also set the stage for the second phase of his career. He had noticed as early as 1898 that when animals were distressed, their stomachs shut down (Cannon, 1898, p. 380). Initially he had seen it is a mild medical condition, which he referred to as "emotional dyspepsia" (Cannon, 1909, p. 482). Only later he discerned that the abolition of digestion during stressful encounters might possess some hidden functional or adaptive meaning.

In trying to make sense of the functional significance of this anomaly, Cannon was led to his theory of the emergency function of the adrenal medulla, more popularly known as the "fight-or-flight response." As he scribbled the idea in a journal in early 1911: "Got idea that adrenals in excitement serve to affect muscular power and mobilize sugar for muscular use – thus in wild state readiness for fight or run!" (Benison et al., 1987, p. 259). The stomach shuts down so that blood can be mobilized for other parts of the body

[3] His first child, a son, was born in 1907, and three daughters shortly followed, mirroring precisely the order and number of his father's progeny. Cannon delighted in those moments when he got to spend quality time with his family (Wolfe et al., 2000, p. 206).

– the parts that need it most during dangerous encounters. Cannon summarized these ideas, and several of his papers, in a 1915 book, *Bodily Changes in Fear, Rage, Pain, and Hunger*.

Cannon's discovery also affected his philosophical orientation, because it demonstrated the value of *teleological* reasoning in science. Until his death, Cannon defended the scientific value of a teleological perspective in the sciences. Upon encountering a novel biological phenomenon, it is not enough to ask: How does it work? What law governs its appearance and disappearance? Rather, one must ask about its purpose or meaning: What is it for? What purpose does it serve in the life of the organism? These questions demand from the investigator what he called a "synthetic" mode of thought that is an indispensible complement to the "analytic" mode of thought. These abstract ruminations on the nature of science are foregrounded in *The Way of an Investigator* (e.g., Cannon, 1945, p. 91).

World War I took Cannon away from his family for over a year and forced him to the front lines of battle as a medical surgeon attempting to make sense of the puzzle of wound shock (see below). He realized that wound shock might result from blood loss, though for a time he mistakenly believed that shock was induced by acidification of the blood. He returned from the war with a more far-reaching perspective – he was ready for a kind of grand synthesis. It was not enough for Cannon to invent a new theory; what was needed was a new paradigm, a whole new way of attacking the body. He found it in homeostasis.

Homeostasis refers to the capacity of the body to maintain the stability of diverse internal variables, such as temperature, acidity, and water level, in the face of constant environmental disturbance. Stability is not a passive property, like mass or weight, but something that must be actively maintained against the forces of dissolution. Although he used the term 'homeostasis' for the first time in print in 1926, the general perspective of physiological function that the term expressed was one that Cannon had been developing for several years prior to that.[4] In light of homeostasis, Cannon could view the emergency function as merely a special case of a highly general biological phenomenon, that is, as an extreme example of a stability-preserving defense. In 1930, W. W. Norton, the head of the American publishing company by the same name, approached Cannon about writing a popular science book. The allowed Cannon to summarize his ideas on homeostasis in his famous *The Wisdom of the Body* of 1932. The book was critically and commercially successful and a second edition was published in 1939. Cannon wrote a second popular book for Norton, *Digestion and Health*, in 1936.

During the 1920s, he also broached his controversial theory of emotion. In a 1927 paper, he summarized his thoughts on the thalamic basis of emotion, and developed a thorough critique of the visceral theory of emotion attributable to his former Harvard philosophy professor and friend William James (1842 – 1910), often known as the "James-Lange" theory of emotion, in homage to the Danish physician Carl Georg Lange (1834 – 1900) who developed a somewhat overlapping view independently of James in the 1880s. James view' was that emotions are akin to perceptual experiences; an emotion such as anger is constituted by the perception of the various bodily changes, and particularly the visceral changes, involved in anger. As James' famously put the idea, "we feel sorry because we cry, angry because we strike, afraid because we tremble…" (James, 1890, p. 450). A crucial consequence of James' theory is that there are no "special brain areas" for emotion, or at least none over and above those for perceptual processing generally (James, 1890, p. 474). Lange, similarly, attempted to explain emotion in terms of the perception of physical changes; unlike James, Lange held that emotions primarily stem from the vasomotor changes resulting from perceiving or remembering various events (Lange, 1912, p. 678). In retrospect, Cannon's critique was devastating for James' theory, most importantly because it shifted the biological study of emotion to the brain sciences (e.g., Ledoux and Phelps, 2008, p. 159).

[4] See, e.g., Cannon, McIver, and Bliss (1924); Fleming (1984) provides an important overview of the development of homeostasis.

In the 1930s, Cannon worked closely with Mexican physiologist Arturo Rosenblueth (1900 – 1970), who worked as an instructor in Harvard's department of physiology from the mid-1930s until 1944, when he accepted a permanent post at the Institute of Cardiology in Mexico City. Cannon and Rosenblueth published their work on chemical transmission in a 1937 book, *Autonomic Neuro-effector Systems*. Though Cannon was mistaken about the precise taxonomy of hormones he suggested, he provided important evidence for the chemical nature of neurotransmission. Rosenblueth also worked closely during the 1930s with American cyberneticist Norbert Weiner (1894 – 1964) and was one of the core members of the blooming cybernetics movement. Rosenblueth even co-authored, with Wiener and American engineer Julian Bigelow, an important philosophical paper on teleological reasoning in science (Rosenblueth et al., 1937). Thus, in addition to his work in physiology, Cannon probably had an indirect impact on both engineering and philosophy in the twentieth century.

Cannon devoted much of the last decade of his life to international humanitarian work. In 1933, he joined the anthropologist Franz Boas (1858 – 1942) in an emergency committee to help scientists that had been expelled by the Nazis. Cannon worked tirelessly to help relocate the Austrian pharmacologist and Nobel laureate Otto Loewi (1873 – 1961) after the latter's arrest and expulsion following the Nazi invasion of Austria in 1938. With the support of Forbes, he also helped another Austrian physiologist, Ernst Theodor von Brücke (1880 – 1941), obtain an appointment at Harvard. In 1937, he became the national chairman of the Spanish Medical Bureau, which provided medical support to Spanish Republicans in the brutal aftermath of Franco's military takeover – a position for which he received intensive criticism and even government scrutiny. In 1939, the House Un-American Activities Committee, known at the time as the Dies Committee, briefly placed Cannon on a list of "distinguished citizens whose Americanism has been called into question" (Wolfe et al., 2000, p. 366). In 1941, he became chair of the medical division of United China Relief, and later one of its directors.

His writings reflect his political orientation. They are infused with the recognition that, just as the body is equipped with diverse mechanisms for maintaining stability, so too is society. *The Wisdom of the Body* culminates with a discussion of "social homeostasis." (Cannon almost excluded the chapter as too speculative; he decided to retain it under Norton's enthusiastic encouragement.) Both the individual organism and society exhibit a division of labor. They both show a gradual evolution from clumsy, uncoordinated movement to sophisticated adaptation to various contingencies. They both require the efficient transportation and distribution of material resources. Cannon envisions an ideal society as one in which the state guarantees the basic needs of each individual and intelligently regulates competition for the benefit of all. Fascism and dictatorships represent strains upon capacity of the social body to adjust itself to changing circumstance; democracy is the only method by which the social body can make the appropriate adjustments in times of change.

In 1944, Cannon penned his memoir from the comfort of his New Hampshire farmhouse. Yet he was not the only writer in his household. His wife, Cornelia, authored a children's book for Houghton Mifflin in 1926, and went on to write two novels. The first novel, *Red Rust*, was published in 1928 and became a bestseller. It was about a farmer who developed a strain of wheat resistant to rust disease. Her second novel, *Heirs*, struggled as a result of the Great Depression.

The Radio Gunner

Alexander Forbes' *The Radio Gunner* is a work of science fiction published anonymously by Houghton Mifflin in 1924. It envisions another, second world war, one that takes place in the late 1930s. An evil empire based in Constantinople vies for world domination and manages to gain the allegiance of Russia and the Mediterranean countries. An aging American physicist, Jim Evans, volunteers his talents in radio engineering. His goal is to install radio detection devices in American ships. These devices have two main purposes: to detect and locate enemy submarines, and to transmit coded messages to allies. The Secretary of the Navy, Sam Mortimer, regularly arranges secret meetings with Evans to discuss military strategy. Through mechanical ingenuity and psychological insight, Evans is instrumental in forcing the enemy to surrender. Moreover, he accomplishes all of these things despite a cast of villains. These include a pompous, red-faced admiral and a sneering commander, both of whom baulk at the suggestion that tried-and-true American equipment be replaced by new-fangled vacuum tubes of British design. Clearly, one of Forbes' aims is to take jabs at some of the stubborn Naval officers he sparred with during his service in World War I (see Forbes, 1922b).

It is valuable to read Forbes' novel in the context of his scientific work at the time, particularly insofar as his work centered around a specific instrument that transformed early nerve physiology, the vacuum tube (Frank, 1994; Kevles and Geison, 1995; Finger, 2004). In 1904 and 1905, the English physicist J. A. Fleming of the University of London patented the two-electrode vacuum tube – also referred to as the "diode," "oscillating valve," or "Fleming valve," – for the detection of radio currents. In 1907, the American inventor Lee de Forest improved Fleming's design by interposing a third electrode, or "grid," between the filament and plate. The three-electrode vacuum tube – also known as the "triode" or "audion" – functioned as a powerful amplifier of radio signals as well as a detector. Engineers soon began to use the triode not only in wireless radio communication but also as a repeater for long-distance telephone signals. Several countries used the vacuum tube throughout World War I for the purpose of amplifying radio signals in military communication.

During the war, several individuals independently arrived at the idea of using the vacuum tube to amplify the electrical activity of nerves for the purpose of recording them. The problem was that the recording technologies available to nerve physiologists during the first two decades of the century, including the string galvanometer, capillary electrometer, and cathode ray oscilloscope, were not nearly sensitive enough on their own to record the disturbances propagated through a single neuron – even setting aside the mechanical problems of isolating a single neuron to record its activity (Frank, 1994; Kevles and Geison, 1995). Some historians have claimed that Forbes was the first person to apply the vacuum tube for this purpose, but this honor probably goes to the German physiologist Rudolf Höber in 1919 (Höber, 1919). Nonetheless, Forbes' naval experience during World War I gave him a facility with the tubes that he used to his advantage, and he established a clear protocol for its use in a research report co-authored with his student Catherine Thacher (Forbes and Thacher, 1920).

In taking the vacuum tube from the context of radio engineering into the field of nerve physiology, Forbes wasn't merely adopting a piece of technology to pursue his work. He was adopting a certain way of conceptualizing the activity and function of nerves, namely, as *signal systems* or *information carriers*. Forbes was not only preoccupied with the *application* of communications technology to nerve. More strikingly, in Forbes' eyes, the nervous system itself *is* an elegant and efficient marvel of communications technology, the function of which is to transmit messages, signals, and, more generally, information about the environment from the peripheral nervous system to the brain. In a 1922 review piece on nerve physiology, he adroitly summarized the function of neurons: "The nerve fiber apparently exists for the purpose of transmitting messages to remote parts, rapidly, economically, and without modification" (Forbes, 1922a, p. 361).

Forbes' statement was prescient; although Helmholtz and other pioneers had compared the nervous system to communications technologies, such as the electrical telegraph (e.g., Lenoir, 1994), such figures of speech were surprisingly rare amongst nerve physiologists during the first three decades of the twentieth century. Terms such as "message," "signal," and "information," are absent, for example, in Sherrington's *The Integrative Action of the Nervous System* of 1906; they are absent from the writings of Herbert Gasser prior to the 1930s; they are absent from the work of Alan Hodgkin, with a single exception which describes the nerve impulse as a "sensory message" (Hodgkin and Huxley, 1939). With few exceptions, physiologists at the time described nerve action in terms of the physical language of "impulses," or "disturbances." Neuroscientists' preoccupation with the coding and decoding of neural "messages," and the quantitative measurement of the flow of "information" in neurons, only became commonplace by mid-century, in the aftermath of the cybernetics movement (Kay, 2001; Heims, 1991). Thus, Forbes was substantially ahead of his time in thinking of the fundamental function of the neuron in terms of the transmission of information, though Adrian soon adopted this way of speaking as well (Garson, 2003).

What we see in reading Forbes' scientific and literary work in parallel is a kind of deterioration of the line between the biological and the social realms. In his 1922 review article, the nervous system as a whole becomes little more than a set of relays for channeling messages. In *The Radio Gunner*, the reverse transformation takes place: the American Navy becomes little more than a nervous system, a mechanism that obtains and relays information for the sole purpose of coordinating its activities. Biological systems become humanized; human societies become biological systems. This latter transformation is illustrated in several passages. In one, Evans describes the analogy between the military and the nervous system to Mortimer:

> "It always seemed to me," said Evans, "that a navy could conveniently be likened to a living organism, a man, for instance…Nerves carry the impressions from the sense organs to the central station, the brain, where information is sorted into the springs of action…Now in the navy your patrols, scouts, planes, drifters, etc., with their observers and hydrophones, and all forms of radio receiving apparatus, are the senses…In place of the muscles, fists, and teeth you have the ships' engines and the guns, torpedoes, bombs, and such like. The nervous system is the general staff which determines policy, the admirals who execute it, and communications which are the nerves that bring information into the navy's brain, and in turn give the word for action." (Forbes, 1924, p. 30)

The Radio Gunner is not only prescient because of the way it showcases this information-based conception of the nervous system. In addition, it expresses Forbes' realization that future wars would be won or lost not by military brawn alone, but also by the efficacy of communications technology, including the coding, decoding, transmission, and interception of messages. This realization is woven throughout the novel. For example, as he informs Mortimer:

> The average naval officer takes far more interest in ordinance and gunnery than he does in communication…[but] just as the skill and wisdom of the gunnery officer direct the titanic force of the guns to the point where it is most telling, so the controlling mind, acting through communications, directs the first of the entire fleet; that's the field where the minimum energy will yield the largest return; put your best efforts in there. (Forbes, 1924, pp. 30-31)

In another passage, he celebrates the untold power of the vacuum tube:

> One improvement in particular, a new type of vacuum-tube transmitter which they had recently perfected, far surpassed anything that had yet been seen, and by its efficiency in eliminating interference it opened such extraordinary possibilities in the scope of fleet communications that without it the navy would be lagging sadly behind the more progressive Allies. (Forbes, 1924, p. 58)

The Radio Gunner was not Forbes' only literary venture, nor was it his last. Two years earlier, Forbes published a short, lively account of the uphill battles he faced in convincing obstinate Navy captains of the utility of the radio compass or "direction finder." This account appeared in a Boston-based outdoors magazine, *The Open Road* (Forbes 1922b). A year after the appearance of *The Radio Gunner*, he wrote a humorous monograph about a boating expedition he'd taken as a Harvard student with his friend, Gerrit Forbes, and their two dogs, through Bighorn Canyon in Montana. In one particularly memorable image, Forbes describes disembarking and wandering through a small Mormon town, hot and exhausted, hoping to find a beer. The episode was published in a book by the explorer Edward Gillette, who had made the same expedition a decade earlier when the same river was covered in ice (Gillette, 1925).

Forbes' most ambitious literary project after *The Radio Gunner* was a book-length narrative about his reconnaissance mission, during World War II, to identify promising locations in Labrador for building an airstrip that would help transport fighter planes from the US to England. Although the eventual airstrip was never used for transporting fighter planes (it was used as a weather station), Forbes thought that the tale of exotic lands, encounters with indigenous communities, and a host of eccentric characters led by the ship's captain, the Arctic explorer Bob Bartlett, would make for an irresistible adventure.

Sadly, he failed to drum up support from most of the publishers he contacted. A string of polite rejections from publishers such as Little, Brown, and Co., W. W. Norton, and Houghton Mifflin, shared the same two concerns. First, the nature of the mission had little general appeal. But more importantly, the terse, factual, descriptive skills that had served Forbes so well in his scientific career utterly failed him in this literary endeavor. His descriptions, the publishers complained, read like a dry parade of facts; they were devoid of the life and color that audiences would demand. As a representative of Little, Brown, and Co., put it, in a letter of September 27, 1945, "Since you ask me to be candid, I must say that I think the sample is perhaps too unadorned with detail to carry the reader through a book" (Alexander Forbes papers, Box 48). As Harvard University Press counseled him in 1948, "The interesting localities and personalities must be made vivid and living through really first-rate writing" (Alexander Forbes papers, Box 48).

Their complaint was not entirely unfair. Here is a representative passage:

> By September 25 the plans were fast taking shape and the loads removed from the *Sicilien* were being stowed aboard the trawlers. Hubbard, fearing that the seven ships on hand would not suffice to carry the load, started a search for another, and soon found that Carlson, owner of the *Polarbjorn* and the *Quest*, knew of a similar ship, the *Selis*, belonging to the Norwegian Navy and now at Lunenburg, an eight hour's journey to the west along the coast. (Forbes, 1953, p. 20)

Forbes, for his part, promised to do what he could to enliven the narrative. Undeterred, he continued to write the manuscript. In 1952, several years after he began soliciting the proposal, Harvard University Press agreed to publish the book on the condition that Forbes subsidize part of the manufacturing costs. The press also assigned him an editor to spruce up the story. It was published a year later (following clearance by the Department of Defense) as *Quest for a Northern Air Route* (Forbes, 1953). Although the book only sold a few hundred copies, Forbes' persistence was rewarded with a deluge of warm letters of appreciation from friends and colleagues to whom he had given the book. The present author's sense is that Forbes, now in his 70s, was not primarily seeking a commercially successful book; rather, he wanted to craft a permanent record of his final major adventure.

The Way of an Investigator

In *The Way of an Investigator*, Cannon cheerfully blends several genres. It is partly a memoir, partly a catalog of the virtues of the scientist, partly sage advice to young men and women considering a career in science, and partly what the philosopher of science Karl Popper referred as a *Logik der Forschung* – a philosophical attempt to discern a set of maxims to propel scientific discovery, rather than guidelines for the justification of existing theories. Thirty years after its publication, his former colleague Hallowell Davis clearly recognized Cannon's book as an important contribution to the philosophy of science (Davis, 1975).

W. W Norton himself, in letters to Cannon, indicated his view that one of the most important features of the book was its pedagogical value, in that it would serve as a beacon and guide to young scientists entering the fray. In a letter to Cannon of February 20, 1945, Norton encouraged him to develop an index: "I think it would be a very grave mistake to have no index whatever in this book. Were the book a straight autobiography, I would not press the point. But I believe in all sincerity that this book of yours will live for many years as the guide, philosopher, and friend to young people thinking about or actually entering upon a scientific career" (Walter Bradford Cannon papers, Box 172). Many of the newspaper reviews of the book, which the Cannons proudly collected in a scrapbook, also indicated its instructional value for the young scientist. Cannon was a teacher at heart.

Even those chapters that are most autobiographical tend to function, for Cannon, merely to illustrate some maxim or precept of scientific wisdom. For example, in one anecdote, Cannon described how he forgot his house keys and had to sleep at a friend's house (the philosopher Ralph Barton Perry). Unbeknownst to him, his wife and sister were awake and, by dawn, led an impromptu search party with his colleagues and friends along the Charles River. Yet Cannon ultimately used this story as mere fodder for a moral lesson about the all-too-human tendency to make unsupported assumptions. Incidentally, the anecdote probably reveals something about the depths of despair that Cannon was prone to. Cannon relates that during this episode, he had been through a rough patch in his research and Cornelia was worried that he had killed himself. (Benison et al., 1987, p. 149, also note the revealing quality of the passage.)

The literary heart of the book, however, falls almost at the mid-point of the volume, breaking it neatly in two. In "A Parenthesis of War," he broke decisively from the pedagogical mode and sketched a portrait of his experiences studying wound shock on the battlefields of France. In one episode in mid-1918, a German bomb burst near their hospital in Chalons-sur-Marne; soon after the explosion, "the flood of torn men began to pour in" (Cannon, 1945, p. 139). Shortly afterwards, as he rode in a supply truck headed south, he described images of fleeing refugees:

> …a woman and a boy carrying gas masks and pushing a baby carriage full of family treasures; great carts laden with bicycles, hay, bedquilts, bread, old women, babies, clothing; dogs and goats trotting along beside the walking people; a young girl or middle-aged woman leading the horses, sometimes an old man leading; carts standing before the horses and people hurrying to get out their belongings – no tears or crying, no complaining; the fields rich with grain, just turning yellow and ready for the harvest, under the blue, cloud-flecked, summer sky; all nature lovely and joyous, if it were not for the hideous cruelty of war. (Cannon, 1945, pp. 139-140)

He also described the experiences in a typical shock ward:

> Men with their bellies torn open, with the sides of their faces ripped out, with brains oozing from skull wounds, with the bladder shot through, with sucking chest wounds – such were the pathetic, well-nigh hopeless cases left in the ward…Cursings, expletives, repeated shouts for "mother" or for "mama" or "papa," and the stench of purulent wounds and dressings made the shock ward a heart-wrenching place. (Cannon, 1945, p. 140)

Though Cannon used the narrative to draw attention to some of medical advances forged on the battlefield – most notably, that wound shock might be a function of blood loss – he duly noted that these medical advances did nothing to vitiate the senselessness of suffering from which they emerged: "We grasp at any gains which can be set against the appalling losses of war" (Cannon, 1945, p. 135). This chapter doesn't merely serve to dramatize the war. In addition, it helps to contextualize Cannon's devotion, particularly during the last decade of his life, to international humanitarian assistance, as well as to scientific collaboration across national borders. In fact, he sometimes rebuffed the criticism he received for his political actions by pointing to the horrors he had personally witnessed (see Wolfe et al., 2000, p. 451).

Conclusion

There are several reasons why scientists may choose to express themselves through literature. Through fiction, and in particular, science fiction, scientists are free to imagine novel technologies, such as the power to create life in a laboratory, or delete awful memories with ease and precision, and are free to grapple with the ethical problems that may arise from them. Alternatively, scientists can freely imagine *new uses* for existing technologies, or the consequences of the *widespread adoption* of existing technologies. One may imagine, for example, a world of genetic modification run haywire, or a world where people chose to forego the benefits of globalization and transition back to small-scale rural lifestyles, or a world where psychological manipulation techniques are used for brutal social repression. Such documents have inestimable value for the historian of science, for a number of reasons – not the least of which that they illuminate the kinds of social and psychological tensions that existed at the time that those documents were produced.

This is particularly true of *The Radio Gunner*, a work of science fiction that envisions the widespread wartime adoption of radio broadcasting technology. Although much has been written on the centrality of communications technology and theory during World War II (e.g., Kay, 2001; Heims, 1991), Forbes' novel reveals that there were perceptive individuals even decades before that understood that communication and coding are key to military endeavors. If Forbes had not penned his novel, this fact could be easily overlooked.

Another major value of reading the literary memoirs of scientists is that they can illuminate the style of thinking, chain of ideas, or serendipitous experiences, that may have led to important scientific advances. (Cannon himself emphasized the role of serendipity in the process of discovery.) Naturally, such *post hoc* reconstructions of science must be taken with a grain of salt, as a scientist may be prone to provide a misleadingly rationalized revision of the sequence of ideas, or have a vested interest in establishing a priority claim (or even settling old scores against opponents). Scientists may simply misremember the biographical facts: even the neuroscientist Oliver Sacks, who has written extensively about the vagaries of memory, was genuinely astonished to discovered that important chunks of his autobiography, *Uncle Tungsten: Memories of a Chemical Boyhood,* were not actually true, despite the vividness of his apparent recollections.[5]

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[5] See Sacks' article for the *New York Review of Books* of February 21, 2013, titled "Speak, Memory." http://www.nybooks.com/articles/archives/2013/feb/21/speak-memory/, accessed March 5, 2013.

Yet despite these misgivings, scientists' reconstructions can often be cross-checked against archival or published work, and can yield evidence about the character of the scientist and the conditions of his or her research. From the perspective of the philosophy of science, literary memoirs can be particularly valuable in the way that scientists' reconstructions of the process of discovery may provide evidence for various theories of scientific reasoning. Cannon's *The Way of an Investigator* may be particularly valuable in this respect.

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