

also discovered the positive and negative "mesotron," now called the muon. Thus he added three new fundamental particles to physics and pointed the way to the existence of antimatter. At age 31, Anderson was then the youngest person to receive the Nobel Prize. (Tsung-Dao Lee got the 1957 prize when he was 30.) Anderson wrote this autobiography during five years, beginning in his late seventies, at the request of his son and daughter-in-law, David and Melanie Anderson, who did the preliminary editing after his death.

Anderson began his long career at Caltech as an undergraduate. Then came his PhD thesis on photoelectrons produced by x rays, under the nominal direction of Robert Millikan. ("For this I thanked him," Anderson wrote, "but not once during the three years of my graduate thesis work did he visit my laboratory or discuss the work with me.") Then came postdoctoral work, again, loosely supervised by Millikan, during which Anderson built and ran the Caltech Magnet Cloud Chamber.

For this project, Anderson built a large vertical cloud chamber and a heavy air-core magnet that produced a field of 25 kilogauss. When he first put the unwieldy apparatus, resembling an "obese pig," into operation, Anderson obtained "dramatic and completely unexpected" results: approximately equal numbers of positive and negative particles where only electrons were expected.

Anderson continued the measurements with his first graduate student, Seth Neddermeyer. They first interpreted the thin "wrong-curvature" tracks they observed as upward-moving electrons. However, with the insertion of a lead plate in the chamber, the change in curvature above and below the plate showed the particles' direction of motion. The first track thus analyzed turned out to be an upward-moving positive electron! This event, and subsequent data, led to Anderson's Nobel Prize.

To obtain more intense, higher-energy cosmic rays, the pair transported their magnet cloud-chamber to the summit of Pikes Peak, Colorado. Analyzing the cloud-chamber photos after a summer at the Peak, they found positive and negative tracks that were different from electrons and protons and appeared to have intermediate mass. While they were still pondering their high-altitude results, Millikan ordered the cloud chamber and its team to Coco Solo, in the Panama Canal Zone, to investigate the lat-

itude dependence of sea-level cosmic rays. After their return, toward the end of 1936, Anderson and Neddermeyer proposed that the high-altitude tracks were new, unknown particles that (on account of their mass) they called "mesotrons."

Succeeding chapters of Anderson's autobiography deal with the award of the Nobel Prize, the development of rocket launchers at Caltech during World War II, and Anderson's postwar cosmic-ray research using a B-29 bomber. An interesting (and apparently little-known) wartime episode involved Anderson's being asked by Arthur H. Compton in May 1942, "to head a project to design and build an atomic bomb." Anderson turned it down "on purely economic grounds." Five months later, General Leslie R. Groves offered the job to J. Robert Oppenheimer, who accepted. Anderson observes: "I believe my greatest contribution to the World War II effort was my inability to take part in the development of the atomic bomb. Thinking so brings me peace of mind."

Anderson's autobiography gives valuable insights into the early days of cosmic-ray and elementary-particle research in America, and especially at Caltech. He describes his barely funded research and tells of the joys and challenges of "small science," remarking: "To find the positive electron and the two muons cost about \$15,000."

This small book is well worth reading, but I must say (to put it gently) that it is seriously under-edited. Thus, Anderson describes the cloud chamber as counter-controlled, but fails to mention the role played by Patrick Blackett and Giuseppe Occhialini, at the University of Cambridge, who invented the coincidence counter-triggered cloud chamber in 1932 and who observed and identified electron-positron pair production. Nor does Anderson point out that Cecil Powell, Occhialini, and Cesare Lattes, at Bristol, discovered Hideki Yukawa's nuclear-force meson in 1947. In fact, the unwary reader could easily conclude from Anderson's account that the Anderson-Neddermeyer "mesotron" (now known to be the muon) was the particle predicted two years earlier by Yukawa and not a confusing look-alike. In his account of the Nobel Prize award, Anderson never mentions Viktor Hess, the discoverer of cosmic rays, with whom he shared the prize. A few editorial footnotes could have avoided these omissions and possible misconceptions.

Also, figure 4 is printed upside down, so it looks exactly like a down-

ward-moving electron, and not an upward-moving positron as it should. The captions are exchanged on figures 25 and 26.

These criticisms aside, I am glad that the autobiography of this remarkable scientist has become generally available, and I enjoyed reading it.

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A Radar History of World War II: Technical and Military Imperatives

▶ Louis Brown
IOP, Philadelphia, 1999. 563 pp.
\$38.00 hc ISBN 0-7503-0659-9

When World War II is called "the physicists' war," the image evoked is of the mushroom cloud over Hiroshima. But nuclear weapons merely administered a horrific *coup de grace* to an already-defeated enemy. Radar, on the other hand, played a pivotal role in key battles that turned the tide of war in favor of the Allies, and for that, too, physicists can claim a fair share of the credit. Louis Brown, a nuclear physicist at the Department of Terrestrial Magnetism of the Carnegie Institution in Washington, DC, offers in this book a compendious and scholarly history of the development of radar.

The idea of using radio waves for echolocation dates back to the early years of the twentieth century, but it was not until the mid-1930s that all the key elements were in place: transmitters and receivers in the meter-wavelength band, modulators capable of generating microsecond pulses, and high-speed cathode-ray tubes to display the results. Most of these developments were byproducts of civilian work on broadcast television. At that time, laboratories in the US, Britain, Germany, and the USSR had all begun radar experiments on a modest scale. Japan did not take notice until 1941, but then hurried to catch up. As a result, all of the principal belligerents in the war entered it with some capability in radar.

Only Britain, however, had thought through the tactical use of radar in a real battle situation. This was a product of the vision of Air Vice-Marshal Hugh Dowding, who conceived a system based on the "Chain Home" (CH) radar network, linked to filter centers that evaluated the pic-

ture and relayed it to the fighter squadrons within minutes. Although many factors played a role in the 1940 battle of Britain, Brown concludes that in this closely-fought combat the British edge in radar proved decisive. He feels, however, that radar has been given too much of the credit for Allied victory in the antisubmarine battle of the Atlantic. In the naval war in the Pacific, though, it gave the US Navy a significant advantage.

CH was obsolescent from the day it was installed, in comparison to the meter-wave equipment already available in the US and Germany at that time. CH operated in the 10–15-meter band, which cursed it with poor resolution and high noise levels. This was a consequence of the technological conservatism of Robert Watson Watt, the British physicist who headed up its development. Watt chose to go for, as Brown reports, "... third best, because second best takes too long and best never comes." But second best, meter waves, was already available from Britain's EMI television laboratories, and best came as soon as 1940, with the development of the cavity magnetron. This device had been independently invented (but not exploited) a few years previously in the USSR, Switzerland, and Japan.

With Britain's limited resources fully committed, a fateful decision was made to bring the US into the picture via the celebrated "black deed box" that carried a magnetron across the Atlantic in September 1940. The Americans moved quickly. The Radiation Laboratory opened in 1940 at MIT under the leadership of Lee DuBridge. A staff was hastily recruited, much of it from the nuclear physics community, and work began by mid-December. Within three months an airborne prototype was flying. Close cooperation with the existing radar programs of Bell Laboratories, the Army Signal Corps, and the Naval Research Laboratory created a formidable presence in radar development.

Complementary to the radar effort was the push for the proximity fuse, essential for effective anti-aircraft fire. Work on the fuse began at the Carnegie Institution under the leadership of Merle Tuve. As the work expanded, it came under the aegis of Johns Hopkins University, creating the Applied Physics Laboratory. By war's end over 22 million fuses had been produced, at a final unit cost of only 18 dollars.

By 1943 the Allies could call upon a wide variety of radars specialized for early warning, battle manage-

ment, airborne search, night interception, bombing, and gun aiming. At the start of the war, anti-aircraft batteries had to expend more than ten thousand rounds for every plane they brought down. By its end the combination of the Rad Lab's tracking radar, Bell's electronic analog gun director, and the proximity fuse assured that once a hostile aircraft was locked in a radar beam, its fate was sealed.

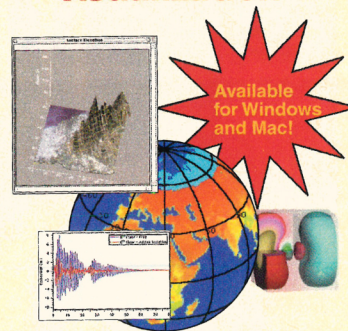
Germany offers a case study in squandered opportunity. By 1938, meter-wave radars of excellent quality were available, largely developed in private industry and sold to the armed forces. But it took a long time for radar to gain acceptance from the High Command. Hitler and Göring disdained it as a mainly defensive weapon. Besides, they harbored a deep mistrust of scientists and engineers. Interservice rivalries and the hidebound traditions of the officer corps also hampered progress. It was not until 1944 that an air defense system as effective as Dowding's went into operation in Germany, and a few months later it was trumped by the arrival of long-range fighter escorts.

The USSR may well have had the lead in radar technology in 1934. But this advantage was dissipated through bureaucratic fragmentation, disinterest at the top, and the disappearance of key personnel in the purges of the late 1930s. Crude early warning radar did play a role in the air defense of Leningrad and Moscow. In any event, however, radar could have had little impact on the titanic land battles that ultimately crushed the German war machine.

Wartime radar work brought significant peacetime dividends. New hardware and manufacturing capacity facilitated the rapid spread of television, FM radio, and VHF and microwave communications. Radar itself made all-weather air and sea travel routine. And today most kitchens in the developed world boast a cavity magnetron, dedicated to such mundane tasks as warming up leftovers.

Brown provides an excellent appendix, outlining the scientific basis of radar in terms a lay reader can easily comprehend. Unfortunately, the writing of the main body of the text is of uneven quality, occasionally marred by mangled sentences and misused homonyms. For this I must fault the publisher more than the author: The computer has not yet rendered redundant the honorable profession of editor. A work of this importance deserved more careful treat-

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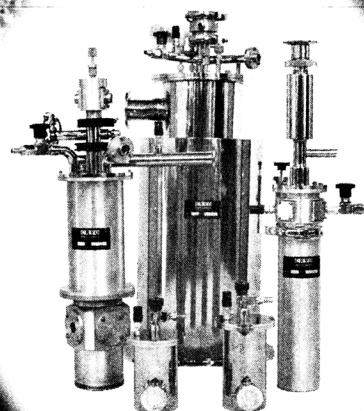
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ment. Nevertheless, Brown tells a fascinating story, and this book can be hard to put down.

ROBERT H. MARCH

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Encyclopedia of Volcanoes

▶ Edited by Haraldur Sigurdsson,
Bruce F. Houghton,
Stephen R. McNutt, Hazel Rymer,
and John Stix
*Academic Press, San Diego, Calif.,
2000. 1417 pp. \$99.95 hc
ISBN 0-12-643140-X*

The *Encyclopedia of Volcanoes* is the product of many years of concerted effort by 112 well-qualified contributors. It is certain to become a standard reference on nearly all aspects of volcanism. Its 82 articles are grouped by editors Haraldur Sigurdsson, Bruce F. Houghton, Stephen R. McNutt, Hazel Rymer, and John Stix, into nine sections dealing with the origins of magmas, eruptive processes, explosive and effusive volcanism, subaqueous and subglacial eruptions, volcanogenic ore deposits, geothermal energy, hazards, and cultural aspects of volcanism. Each article is designed to stand on its own. This has the disadvantage of much repetition (and occasional inconsistencies) and makes the book a good bit longer than necessary. But, with few exceptions, the balance of topics is both broad and comprehensive.

One might not appreciate the true scope of the volume from reading the introductory chapter, "History of Volcanology." This is essentially a condensation of Sigurdsson's recent book *Melting of the Earth*, (Oxford, 1999), in which he discusses his favorite topic, decompression melting, but without mentioning basic eruptive processes or the historic eruptions in which they were first recognized.

The first section (Part I) of the main text deals with the origin and transport of basaltic magmas. I found three articles particularly impressive. The chapter on volatiles in magmas is an excellent summary of a very complex topic. Equally useful is an article on physical properties, which presents almost all the important rheological and thermodynamic properties of magmas in terms of equations of state rather than the usual graphical curves. Similarly, the discussion of magma ascent at shallow levels is the most lucid and concise treatment of

basic eruptive mechanisms I have yet encountered. Much of the material in the rest of this section is repetitious and not always consistent from one chapter to the next. For example, an article on magma chambers tells us that volcanoes are not underlain by large magmatic intrusions, whereas the later article on calderas calls upon large bodies of fluid magma to explain caldera collapse and the huge outpourings of magma that usually accompany caldera formation.

A second section, dealing with the distribution, sizes, and rates of eruptions, includes thoughtful conclusions that Tom Simkin and Lee Siebert draw from their invaluable record of global volcanism. Two articles on sizes and rates of volcanism are informative but less comprehensive than one might like. In a discussion of subduction-related volcanism, for example, we are told that there is no correlation between rates of subduction and volcanism, despite the good correlations found in the Aleutians, Antilles, and Central America, to name only three.

Effusive volcanism is treated in nine articles (Part III), including especially notable ones on the general nature of lava flows and on volcanic fields, flood basalts, and submarine volcanism. The only important topic missing here is large siliceous ignimbrites. Although these are among the most voluminous eruptions on Earth, they are almost totally ignored. It is said that there are too few careful studies of such eruptions to warrant discussing them! The recent studies of Yellowstone, the Bishop Tuff, or the Valley of Ten Thousand Smokes, to say nothing of earlier ones in Nevada, Utah, Middle America, and Chile, seem not to qualify.

Explosive volcanism, including lahars and debris avalanches, is covered in Part IV, along with calderas, cones, and other morphological features. Most of these articles are informative and well presented, but here, too, I found serious omissions. An article on lahars, for example, makes no mention of regional sheets of volcanic mudflows, such as those of the Tuscan and Mehrtan formations in California. The former covered 5000 km², the latter 30 000 km². Those of the Absaroka Range in Montana and Wyoming covered almost 13 000 km², and even more extensive ones have been recognized in Central America. The articles on phreatomagmatic fragmentation, subaqueous eruptions, and subglacial eruptions are of uneven quality and excessively