of a UNESCO conference. Because of a bureaucratic error, he had a visa for two weeks but only enough funds for the two remaining days of the conference. With typical resourcefulness and a burning desire to see Paris, he rationed his limited resources so that he could buy a round-trip Metro ticket, a sausage and a bag of apples each day while joyfully sampling the sights and sins of Paris.

In a moving story, Shklovsky portrays his 1941 escape from the German attack on Moscow in a train crowded with other students from Moscow University. One of the undergraduates in his train car asked Shklovsky, the senior member of the group, for a physics book to read. Mischievously, Shklovsky gave the young student a German-language copy of Walter Heitler's *Quantum Theory of Radiation*, difficult reading under the best of circumstances. With obvious admiration, Shklovsky, who claimed he "couldn't get through the first paragraph," tells of his surprise when the book was later returned by "the kid," who had apparently read the whole volume with complete understanding. Shklovsky relates how 30 years later he presented the same miraculously preserved book, to that former student on the occasion of the latter's 50th birthday. The recipient was Andrei Sakharov. Curiously, in his own memoirs, Sakharov tells of reading Shklovsky's then unpublished story, but he denies that the event in the train ever occurred. Such is the imperfect memory of great men.

Five Billion Vodka Bottles to the Moon is required reading for anyone—scientist, politician or concerned human being—who wants to understand better the unexpected events now occurring in Russia.

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Fractional Statistics and Anyon Superconductivity

Frank Wilczek
World Scientific, Teaneck, N. J., 1990. 447 pp. $68.00 hc
ISBN 981-02-0048-X; $28.00 pb
ISBN 981-02-0049-8

The quantum mechanics of many-body systems revolves around the requirement that simply relabeling indistinguishable particles cannot alter an observable quantity. In three or more spatial dimensions this restriction permits only two classes of particles—bosons and fermions—depending on whether permuting a pair is accompanied by a phase factor of plus or minus one. A unique feature in two spatial dimensions is that one can keep track of the number of times a particle has encircled another; the principles of quantum mechanics are then consistent with associating a phase with each encirclement. This phase factor is not constrained *a priori*, and it specifies a continuum of possible quantum statistics in two dimensions (in the same way that the ± 1 factor for exchange specifies the two possibilities in higher dimensions). (See PHYSICS TODAY, November 1989, page 17.) Excitations that possess these intermediate statistics, dubbed anyons, are found in the fractional quantum Hall effect. Anyons arise naturally in $(2+1)$-dimensional quantum field theories, and they have recently aroused interest as possible charge carriers in doped copper oxides.

Frank Wilczek's *Fractional Statistics and Anyon Superconductivity* offers a lucid introduction to the elementary physics of anyons. In a relaxed, conversational style, Wilczek leads off the volume with a pair of monographs that discuss the conceptual and formal underpinnings of fractional statistics and address the physics of many-anyon systems. The last three-quarters of the book consists of over two dozen articles reprinted by Wilczek and others.

Since the phase factor associated with carrying one anyon around another specifies the allowed relative angular momentum of a pair, a many-anyon wavefunction must satisfy cumbersome boundary conditions that force it to be multivalued. A more economical way to introduce the required phase factors is by means of the Aharonov–Bohm effect—for example, by formulating anyons as charged fermions (or bosons) attached to magnetic flux lines of the appropriate strength. Wilczek deftly leads the reader through the subtleties of this procedure and shows how fractional statistics arise naturally in $(2+1)$-dimensional quantum field theories with Hopf and Chern–Simons terms as their Lagrangians.

Readers seeking further insight into the conjectured relationship between anyons and high-temperature superconductivity may be somewhat disappointed. The "anyon superconductivity" of the title refers to the superfluidity of certain ideal anyon gases, which support long-lived longitudinal sound modes (and can therefore carry persistent currents) and have a gap to transverse excitations (permitting only irrotational superflow and implying the expulsion of external magnetic fields). As Wilczek notes, the proposed connection between anyon gases and electrons in copper oxides remains quite tenuous, and the discussion of these issues is found primarily in the book's reprinted articles on chiral spin liquids.

Experiments to detect the breaking of time-reversal and reflection symmetries in high-temperature superconductors (which would necessarily arise if anyons were involved) are not encouraging for anyon models. (See PHYSICS TODAY, February 1991, page 17.) A complete discussion of the role of anyons in high-temperature superconductivity (if any) will have to wait for a future edition.

Aficionados of fractional statistics will find many of their favorite articles reprinted here—from Yakir Aharonov and David Bohm's classic 1959 paper on vector potentials in quantum mechanics to Xiao-Gang Wen, Wilczek and Anthony Zee's 1989 work on chiral spin liquids. Because it is the best-known physical phenomenon displaying anyonic excitations, the fractional quantum Hall effect is prominently featured, as are several papers concerning frustrated-spin systems and the superconductivity of anyon gases. These reprints complement an extensive selection of articles on the conceptual and technical foundations of fractional statistics.

This timely volume offers a clear introduction to the rudiments (and some of the esoterica) of fractional statistics. It should be accessible to anyone with a graduate-level background in quantum mechanics and elementary field theory. In addition to guiding the reader around the "circle of ideas" associated with fractional statistics and anyon superconductivity, the book also provides a thought-provoking refresher course in superfluidity and the quantum mechanics of indistinguishable particles.

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Space Commerce

John L. McLucas
Harvard U. P., Cambridge, Mass., 1991. 241 pp. $24.95 hc
ISBN 0-674-83020-2

John McLucas defines space commerce as "those activities in which private companies put their money at risk to offer goods and services that depend on having satellites in orbit." In this book he includes chapters on communications satellites, remote sensing, navigation, habitations in space and materials processing. I found his accounts of these develop-

ments interesting and informative, and the book clearly benefits from his experience as an insider in many of these developments.

I found it striking that a book on commerce contained very few numbers. For communications satellites, which are by far the most important element of space commerce, McLucas reports that revenues in the US amount to about $3 billion per year. After noting that about $2 billion a year is spent on construction of the satellites and about $1 billion on launching them, he describes this as a $6 billion per year industry!

One good reason for not giving many numbers is that there is so much misinformation in NASA figures. McLucas writes, "As the cost of the shuttle grew, all financial realism in pricing policy went out the window, and prices were set for purely political reasons." This is true for all spacefaring countries. In all cases we deal with command economies. It is therefore not surprising that the cost of launching payloads into orbit has grown as the space bureaucracies have aged. Remember that the energy to launch into low-Earth orbit is about 4.5 kilowatt-hours per pound. That energy was purchased for $1000 in the early 1960s, and the cost declined somewhat for a few years as would be expected for a healthy new industry. "Then in 1978," McLucas writes, "when the Carter Administration threatened to cancel the shuttle because of delays and cost overruns, the shuttle's protectors came up with a proposal that the government should close down every other launch program and force all payloads—commercial, civil, military and foreign—to fly into space aboard the shuttle."

After enforcing the shuttle monopoly on US space launches, the aging bureaucracy has now driven the real costs up by about an order of magnitude. This "central planning" control of the gateway to space has stifled space commerce. The Challenger disaster broke the monopoly and permitted a revival of the more economical expendable launch vehicles of the sixties. But the bureaucracy survives.

I am convinced, and McLucas has strengthened my conviction, that to realize the dreams that have always driven the space program, we must first learn how to dismantle an entrenched command economy. We must profit as much as possible from the painful experiences of Eastern Europe and the former Soviet Union. Only an approximation to a free market can properly exhibit America's capabilities in space commerce.

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Inventing Accuracy: A Historical Sociology of Nuclear Missile Guidance

Donald MacKenzie
MIT P., Cambridge, Mass., 1990. 464 pp. $29.95 hc
ISBN 0-262-13258-3

The subtitle of *Inventing Accuracy*, that it is a "sociological history of nuclear missile guidance," seems designed to raise the hackles of half of its potential readers—hard scientists. Indeed, it leads with the author's chin: How dare a historical sociologist, whatever that is, take on a subject of such technical complexity as inertial guidance? And, since it deals with a politically sensitive topic from a viewpoint that is obviously extremely dovish, how fair to the developers of nuclear missiles can the reader expect the book to be?

Inventing Accuracy may seem to have two strikes against it—its title and its author's background—but the book itself hits a triple, if not a home run. The author, most definitely a sociologist with no claims to a former life as a hard scientist, has taken an arcane topic, the subject of much mythological history handed down through the years, and made the technical brilliance of the *solutions* arrived at not only understandable to a physicist but also to someone from his own discipline. Indeed, figure 2.2, which was adapted from another book, may be the most lucid explanation ever of why a gyroscope precesses; it deserves far wider circulation, in popular and technical works.

MacKenzie asserts and then demonstrates that technical choices have strategic consequences, and he illuminates the roads taken and those passed by. Perhaps, he suggests (and he makes a persuasive case), other simpler and less elegant solutions might have been preferable. In no sense were today's inertial guidance systems the inevitable result of technological movement along a uniquely possible path. Different choices in guidance design might have led to a generation of intercontinental missiles with lower accuracies and lower costs; mutual deterrence enforced by explicitly holding cities hostage might have provided more strategic stability than we have in today's world when many missiles are aimed at other missiles to "limit" damage. However, the political task of explaining such a choice would be even harder than demonstrating the flaws in the concept of strategic defenses.

At the beginning, in 1945 or so, the whole idea of inertial guidance seemed an impossible dream. Of particular interest to physicists will be MacKenzie's tale of "the problem of the vertical," when it was realized that the equivalence principle appeared to rule out a pure inertial guidance system, since acceleration and gravitation could not be distinguished. A plumb bob, MacKenzie recounts, would no longer indicate the true local vertical in an accelerated black box; if one could not know the vertical, then it would be impossible to know whether or not accelerometers intended to be horizontal really were. George Gamow entered the battle with a paper called "Vertical, Vertical, Who's Got the Vertical?"; and P. M. S. Blackett objected to inertial navigation schemes using physical arguments similar to those of Gamow. The solution to the problem is elegant; the reader can work it out or read the book. But a hint may be in order: Consider what would happen if one tried to determine the vertical direction using a plumb bob whose string was equal to the radius of the Earth so that the bob always remained at the center of the globe.

The chapter on Soviet guidance systems, while necessarily far less detailed than those on Western technology, is of extraordinary interest. The author demonstrates that engineers and scientists starting from the same point (the V-2 guidance system) and having access to roughly similar sets of ideas do not necessarily wind up with technically similar solutions to the same problem. And it is not easy to say which solution set is truly better.

The most controversial chapter is entitled "The Construction of Technical Facts." MacKenzie traces the competition between bomber proponents and missile enthusiasts in the US Air Force, shows how the "bomber lobby" eventually lost (although with the B-2 and B-1b they may be making an ill-deserved comeback) and demonstrates that "accuracy" may be more a theological construct than a technical one. The problem in defining a missile's accuracy is not with the reasonably well debunked question of "bias" arising from unknown components of the gravitational field over the Earth's poles or from still-undiscovered electromagnetic forces. Instead, MacKenzie's doubts arise from fundamental questions about the abi-