

The Rise and Fall of the Fifth Force: Discovery, Pursuit, and Justification in Modern Physics

Allan Franklin and Ephraim Fischbach

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Hints of fifth force in universe challenge Galileo's findings," proclaimed a front-page headline in the *New York Times* on 8 January 1986. Written by highly regarded science reporter John Noble Wilford, the article under it revealed that Purdue University's Ephraim Fischbach and colleagues had just published a paper revisiting early 20th-century torsion-balance experiments by Hungarian physicist Roland von Eötvös. Those experiments had helped establish the equivalence of gravitational and inertial mass. Fischbach and coauthors argued that the experiments also revealed subtle evidence for a new intermediate-range force supplementing the fundamental four: gravity, electromagnetism, and the strong and weak nuclear forces.

This "fifth force," as Wilford dubbed it, was about 1% as strong as gravity, extended roughly 100 meters, and could be carried by a light "hyperphoton" that coupled to baryon number. Because that force depended on a material's composition, it would have slightly altered the acceleration rates of the objects Galileo is said to have dropped from the Tower of Pisa.

Fischbach and University of Colorado historian of physics Allan Franklin independently relate the story of the fifth force in the second edition of Franklin's original book, *The Rise and Fall of the Fifth Force: Discovery, Pursuit, and Justification in Modern Physics*. Exposure in the nation's leading newspaper likely catapulted the new result into a prominence it would not have otherwise enjoyed. Wilford's article quickly elicited critical reactions from other physicists. Within days Richard Feynman and Sheldon Glashow had weighed in with disbelief. Others soon pointed out an omission in the authors' reasoning: Such composition-dependent forces could not have arisen unless there were large horizontal asymmetries in the local mass distribution near where the Eötvös experiments had occurred.

Those qualms, however, did not dissuade the experimenters who rose to the challenge of testing a new hypothesis

some considered plausible. Within a year three teams reported in with conflicting results. In one, Peter Thieberger of Brookhaven National Laboratory set a hollow copper sphere adrift in a temperature-controlled, magnetically isolated tank of water placed next to the Palisades in New Jersey. The sphere drifted steadily away from the cliffs, seeming evidence for a slight difference between the forces on water and copper. But a University of Washington experiment led by Eric Adelberger yielded null results. Using an extremely sensitive torsion balance, the Washington physicists suspended beryllium and copper cylinders pivoting about a central axis. Any composition-dependent force would have generated a tiny but measurable torque about that axis, but none was observed. Another University of Washington torsion-balance experiment gave positive results, but they disagreed numerically with Thieberger's conclusions.

In part, the experimental confusion reflected the limited understanding in the late 1980s of any deviations—which had been insufficiently measured—from Newton's inverse-square law at distances from 1 to 1000 meters. Only a few relevant experiments had been conducted, and they did not rule out deviations of up to a few percent. Some results had unattributed errors due, for example, to unaccounted-for mass asymmetries. But that area of experimentation rapidly improved during the late 1980s. By 1990, according to the authors, the fifth force was on its knees. A year later it was dead, with the great preponder-



ance of evidence weighing against its possible existence.

So was all the experimental—and theoretical—effort a waste of time? Not at all, says Franklin in his new discussion. For one, the search for small intermediate- and short-range deviations had an effect on particle-physics theory, particularly on theories of charge conjugation-parity violation and string theories that required such discrepancies. It especially honed physicists' abilities to design and interpret the increasingly precise experiments needed to evaluate such theoretical work.

For scholars of science, argues Franklin, the search also provided a laboratory in which to study what he calls the "context of pursuit." That kind of research activity arises when a hypothesis is sufficiently plausible, and the experimentation costs sufficiently modest, for interested physicists to pursue appropriate measurements despite the likelihood of obtaining a null result. Appearance in the *New York Times* helps, too.

The publication of this revised edition, which includes updates on theory developments and experiments performed since 1991, is very welcome. Fischbach's section gives a detailed, subjective account of his work from 1985 to 1991, the period of his most intense activity on the fifth force. The revised edition serves as a valuable counterweight to Franklin's original account, included in the book, which was dense, compact, and difficult for the uninitiated to follow. I just wish the publisher had kept the book's cost below \$100, for only the fervid few will judge its contents worth its high price.

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Colour How We See It and How We Use It

Michael Mark Woolfson

World Scientific, 2016. \$34.00 paper (239 pp.). ISBN 978-1-78634-085-6

Michael Mark Woolfson, a professor emeritus at the University of York in the UK, has had a long and distinguished career researching x-ray crys-

tallography, the formation of stars and planets, and biophysics. He has also written more than 20 books on topics



ranging from imaging to probability and statistics—an ambitious scope.

Woolfson clearly intends his latest book, *Colour: How We See It and How We Use It*, as a popularization. He hopes to cover his topic, he writes, in “a general broad-brush way without getting involved in the fine details that would only be of interest to professional engineers and scientists.” Although that is a worthy goal, the book contains serious factual errors. Furthermore, the wide-ranging material is disorganized and the topics seem haphazardly chosen, which leaves me wondering why some phenomena were included while others were left out.

Here are a few of the factual errors. In figure 4.1, Woolfson draws an International Commission on Illumination xy chromaticity diagram that includes a line from white (W) to 520-nm green (A). He then says, “The point M, midway between A and W, would roughly correspond to a mixture of spectral green and white with the same intensity.” In fact, a chromaticity diagram is a central projection from a three-dimensional color space, called tristimulus space, that is related to the sensitivity of the eye’s three types of cone cells. There is no physical significance to the distance ratio AM/AW.

In chapter 6, Woolfson discusses retinal photopigment bleaching, the process by which retinal pigment absorbs a photon and is rendered temporarily unable to absorb another one. In the discussion, he makes an incorrect connection between bleaching and the visual process. He appears to equate the eye’s visual response to the “proportion of active pigment”—that is, the remaining fraction of unbleached pigment. In fact, small light-induced fluctuations of intermediate and bleached photopigment are what initiate an electrical response in the eye. The unbleached pigment is like the charge in a battery—available for light stimulation but not itself part of the response.

The core of Woolfson’s error is in figure 6.10, which shows “curves of rhodopsin decay” after a light is turned on. Here, decay is the same as bleaching. However, if active photopigment decayed as quickly as Woolfson indicates, we would essentially be blind after less than a second in daylight. In reality, the photopigment in a normal eye is almost never appreciably bleached when exposed to common illumination. A sec-

ondary error in figure 6.10 is that, contrary to its caption, not all visual receptors have rhodopsin as a photopigment. Only the rods, responsible for vision at low light levels, use rhodopsin.

Other errors are simply matters of terminology. For example, Woolfson recounts the classic demonstration that a white object in a scene looks green through a small green filter, but it looks white if the filter is brought close enough to the eye to cover the whole scene. Then he says, “The light entering the eye in both cases has the same chromatic content.” He should have said “spectral content” because the chromatic (perceived color) content is not the same.

I was surprised that in a book on color, no mention is made of metamerism, a phenomenon in which two light spectra viewed under the same conditions can be perceived to have the same color. In particular, the trichromacy of vision implies that only three primary colors are required to make a match. For that reason, metamerism underlies color-reproduction systems from television to printed photographs, a fact that seems important to a popularization about color.

The style is also disappointing. Woolfson offers no overriding motif or question to launch his book and engage the reader. Color perception occupies several chapters, including chapters 6 and 10, but it is curiously absent from chapters 7–9, which present historical sketches of artistic uses of pigments, dyes, and pottery. At times, ideas jump around from sentence to sentence; for example, a discussion of nonvisual structures in the eye is interrupted by the out-of-context sentence, “The eye operates best at moderate light levels.” There are no references or photo credits to lead a reader to further information. That said, the author provides a good index and includes with each noted innovator that person’s dates of birth and death, nationality, and profession.

One high point in the book is figure 1.10. There, and in its associated discussion, Woolfson presents a retinal-processing model that captures three important visual effects. First, the light-gathering area for a retinal cell increases at low light intensities, which averages out noise. Second, the area decreases at high light intensities, thus increasing spatial resolution. Third, the

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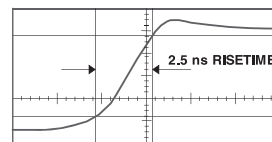
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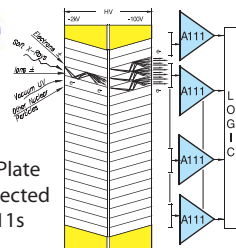
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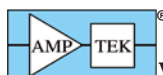
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contrast in neighboring bands of gray appears to be enhanced when the bands are touching, a phenomenon called the Mach band effect. I have seen such a model in technical papers but never in a popularization.

Although I don't view the book as

successful, I respect the author's courage in writing about fields—from evolutionary teleology to cinematography—that are far from where he began.

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Acoustics of Musical Instruments

Antoine Chaigne and Jean Kergomard

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Our experience of sound is created by the motion of the air around us. That motion arises from the movement of nearby objects, whether machines, mosquitos, or musical instruments. Many authors have collected and organized the mathematical equations that predict the motions of the air. Perhaps the first to do so comprehensively was Lord Rayleigh. His *Theory of Sound* (1877, 1894) included everything he could find on the topic, organized in a logical development of ideas and math and largely rendered in the language of differential calculus. It was a singular achievement in its day, and so acute that physicists can still learn much from it.

One of Rayleigh's distinctive contributions was his careful demonstration of the construction of his mathematical models, revealing the assumptions and compromises that limited their predictive abilities. Some of his derivations were unambiguously solid; others employed compromises significant enough to invite the reader's consideration. With characteristic candor, he prefaces the second edition with a confession to his readers: "The pure mathematician will complain, and (it must be confessed) sometimes with justice, of deficient rigour, [but] the physicist may occasionally do well to rest content with arguments which are fairly satisfactory and conclusive from his point of view."

In *Acoustics of Musical Instruments*, Antoine Chaigne and Jean Kergomard have applied mathematical rigor with comprehensive scope, and the result is remarkable. The authors show the readers how each model of musical instrument acoustics is constructed and discuss the effects of assumptions and approximations. The level of detail they provide gives readers greater confidence in what

each model can do—and a firmer understanding of what it cannot. Their observations drive them to build ever more effective models, many using ideas that were not available in Rayleigh's time.

Since musical instruments usually depend on vibrations to generate sound, the authors begin with the simplest equations describing bound motion and oscillation. They expand into traveling waves, modes of vibration, and damping and coupling, and they incorporate nonlinear and discontinuous behaviors. Finally, they model the complexities of design and operation of typical musical instruments, including wood and brass winds, violins, guitars and pianos, and various percussion instruments.

Each kind of instrument is given close attention, as is the listener's orientation with respect to the instrument, since musical instruments often drive different air motions in different directions. The authors' attention to wind instruments is necessarily more extensive in order to encompass those instruments' wider variety of input and output. Unlike string and percussion instruments, whose vibrating parts are made of solids that are relatively unchanging, wind instruments do not themselves vibrate significantly. Instead, they contain air that vibrates. Those vibrations are driven by motions of air inside the performer and are deeply affected by interactions with the air surrounding the instrument. The necessary models predicting the vibrations are developed over several dedicated chapters.

The authors use Newtonian mechanics for their initial simple models, then refine them by incorporating concepts from finite math, thermal and fluid

dynamics, structural analysis, and dynamic systems. Although other books take a similar approach, Chaigne and Kergomard distinguish themselves by patiently introducing their topics, developing and assessing the math, and explaining their subject in a way that prevents any confusion or misunderstanding.

Readers also benefit from the authors' substantial investment in the book, which they have improved through several editions; this is the first English edition of the valuable text, which had earlier appeared in French. Chaigne and Kergomard have drawn from an immense collection of both theoretical and experimental sources, which has yielded a resource that is current, thorough, and packed with citations that can lead readers to deeper exploration.

Chaigne and Kergomard's magnum opus sets a high standard for logical and mathematical rigor in musical-instrument acoustics. The text and math are lucid throughout and should be easily understood by readers with a basic grasp of mechanics. The authors are justified in recommending the book to "students at master's and doctorate levels [and] researchers, engineers and other physicists with a strong interest in music"—each of those groups will find the information they need in *Acoustics of Musical Instruments*.

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