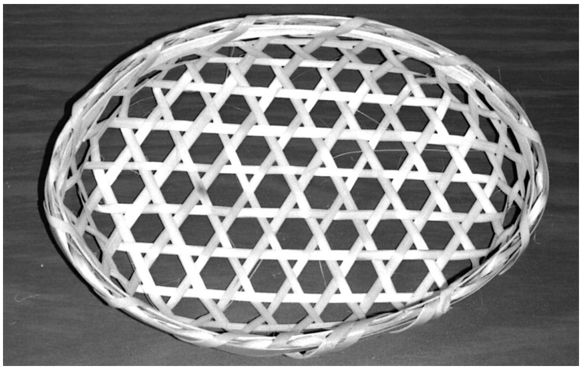
Kagome: The Story of the Basketweave Lattice

The Japanese word *kagome* has become popular with the magnetism community in discussing the lattice structure of geometrical spin frustration. One might guess that this word is the name of some Japanese scientist. But kagome means a bamboo-basket (*kago*) woven pattern (*me*) that is composed of interlaced triangles whose lattice points each have four neighboring points. Now that bamboo baskets have been largely replaced by plastic containers, the word kagome may seem a bit old-fashioned. Who introduced it to denote a special lattice structure? Those who know the answer to that question may belong to the first generation of researchers in frustration study.



Bamboo basket woven in kagome pattern

The 1944 paper by Lars Onsager,[1] who solved the square-lattice Ising model exactly, had a great impact on the study of phase transitions; Onsager's work motivated researchers to extend the study to other lattices—triangular and honeycomb, for example—and to antiferromagnetism. G. H. Wannier's famous paper on the antiferromagnetic triangular lattice is one of the results.[2] Kodi Husimi of Osaka University, and young staff member Itiro Syôzi, also started to explore phase transitions in various lattices. Using a dual transformation, they simplified Onsager's abstract algebraic method and obtained exact solutions for the honeycomb and triangular lattices.[3] As soon as Husimi and Syôzi published their results in 1950, there was a rush of papers about phase transitions on those lattices.

Syôzi studied a decorated honeycomb lattice with an extra spin at the middle point of each bond to obtain the exact solution for an antiferromagnet. He found that the decorated honeycomb lattice turns into a new lattice by star-to-triangle transformation. Husimi's appreciation of art—he painted pictures as a hobby—led him to name this new lattice kagome. The first paper on the subject, with Syôzi as sole author,[4] appeared in *Progress of Theoretical Physics* in 1951. In that paper, Syôzi gave a logarithmic temperature dependence for the specific heat and showed the transition temperature for the ferromagnetic kagome lattice. He also demonstrated that a magnetic transition does not occur in the antiferromagnetic kagome lattice. Because the journal in which he published that paper was a fledgling one with low circulation, his work has only gradually been discovered.

Itiro Syôzi

Two years after the first kagome paper was published, Kenji Kano and Shigeo Naya of the Husimi group calculated the residual entropy of the Ising spin kagome lattice by using a method different from Syôzi's to solve the eigenvalue problem. In 1972, Syôzi reviewed Ising models on various lattices.[5] Subsequent theoretical studies of the kagome lattice in the 1980s covered effects of magnetic field, randomness, second neighbor interaction, spin freedom, and combination of interactions.

Experimentally, the mineral jarosite, with Heisenberg spins on stacked kagome lattices, was first discussed as a model compound 17 years after the first theoretical work.[6] An Ising model run on the kagome lattice has been applied to two-dimensional hydrogen bonding in $CsOH{\cdot}H_2O$ and the second layer of adsorbed helium-3 on graphite.[7] A group at Bell Laboratories revealed that $SrCr_{9-x}Ga_{3+x}O_{19}$ has unusual magnetic properties that have been associated with those characteristic of the kagome lattice.[8] Those properties have attracted much interest among both theorists and experimentalists.

On 18 October 2001, Syôzi passed away at the age of 81. The author of the first kagome paper is gone but the word survives among us.

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Students Need Scientific Habits and Basic Concepts

As a recently retired high-school teacher—my second career after decades in industry—I read Jerry Gollub and Robin Spital's excellent article (PHYSICS TODAY, May 2002, page 48) with great interest. I agree completely that "the promotion of scientific habits of mind is more important than particular choices concerning [course] content." In that regard, I have two comments, directed to teachers of high-school physics.

The advice advanced by the authors is equally applicable to non-AP high-school physics courses. The acquisition of scientific habits of mind is just as important to the fledgling arts major as it is to the science-oriented student. The reduction of junk science used by our next generation of political, social, and environmental leaders would be a welcomed consequence.

A trimming of course content to focus on depth of understanding provides opportunity for a "habits of mind" unit, about two weeks in length, to start the first semester. I found that a stimulating and mind-opening unit can be built around the principles espoused by Arnold Arons in the "Underpinnings" chapter of his classic book, *A Guide to Introductory Physics Teaching* (Wiley, 1990). An underpinnings unit prepares students for an insightful year of physics by shoring up their generally weak understanding of ratios, scaling, operational definitions, and even the meaning of "because"!

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DARI to Go Where Radiation Has Gone Before

The new DARI (Dose Annuelle due aux Radiations Internes) unit proposed by Georges Charpak and Richard Garwin (PHYSICS TODAY, June 2002, page 24) has been defined elsewhere as a measure of the internal "irradiation experienced during a single year by an individual due to the radiation emitted by the radioactive materials present in the human body that have nothing to do with any line of work."[1] Equal to precisely 0.2 millisieverts, the DARI takes into account, as the PHYSICS TODAY article states, "the biological effects of different decay particles." This exposure arises principally from the body's natural levels of potassium-40 and carbon-14; both are sources of sparsely ionizing radiation. Because the sievert numerically equals the gray for such radiation, one DARI equals 0.2 milligray. The sievert is not a directly measurable quantity, because it relies on radiation- and tissue-weighting factors that have been set arbitrarily by committee consensus.[2] However, the gray, the unit of absorbed dose, is a ratio of measurable quantities—the joule and the kilogram.

I suggest that the DARI be related to the gray rather than the sievert. Moreover, I recommend that DARI be interpreted as a threshold of individual sparsely ionizing radiation exposure that would elicit any harmful effect in humans or in any of their