

The output energy required for calculating a country's operating efficiency would be more difficult to assemble. Instead, a simple measure of the total output is the country's gross domestic product. The resulting ratio of GDP to annual input-energy consumption would not be an efficiency, but it would offer a measure of how well a country utilizes its energy for generating wealth. The ratio could be called an efficiency index and is conveniently expressed in terms of dollars per megajoule. The ratio would be valuable in examining long-term trends, if one corrects for inflation, and would also be useful for comparing the operational efficiencies of different countries.

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Farmer, Shubik, and Smith reply: We titled our article "Is Economics the Next Physical Science?" because we are interested in the wide variety of questions of organization that have traditionally concerned economists, but that might also be well formulated as physics problems. The existence of such interesting problems does not presume that human behavior is mechanical. Our article emphasized two major observations that we think provide opportunities for a physical point of view.

First, we live in an institutional world. Without regard to the degree of mechanism in people's behavior, institutions are by their nature mechanistic, and their mechanism can be treated even with relatively modest conceptual advancement from what physics already does well. Much of current econophysics, including some of our own work, is based on explicit models of institutional dynamics that have been omitted from more mainstream economic research, but that can be shown to predict strong regularities in price formation or other economic processes.

Second, the assertion that people are too irregular to be treated mathematically does not follow from the failure of past attempts to do so. The modeling of institutional process is as interesting for its limitations as for its successes, precisely because the regularities left unexplained by pure process models (which we have characterized as "zero-intelligence" models) are potential mathematical regularities of behavior. Readers will judge whether they prefer quantitative, predictive, falsifiable theories to the 19th-century narrative mode of description, but scientific de-

scription clearly provides modes of belief change that narrative does not.

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One thing Einstein didn't do in 1905

As we look back on 2005, the 100th anniversary of Einstein's most creative year, it is worthwhile to remember what he didn't discover—or at least what he didn't tell us he discovered—in 1905. Among the items is the photon.

A "photon"—the name was coined by the physical chemist Gilbert Lewis in 1926—is an elementary particle with energy $h\nu$, momentum $h\nu/c$, and mass zero. In 1905, Einstein discussed an energy quantum only. He did not discuss the quantum's momentum until 1916. On the question of the mass, his 1905 paper contains an odd calculation. He noted that the average kinetic energy for a Maxwell-Boltzmann particle in a distribution at a temperature T is given by $3kT/2$ (in our present notation, not his). He assumed that the Wien spectrum, which he used for high frequencies to exhibit the entropy of the radiation, is valid for all frequencies. He then calculated, in his notation

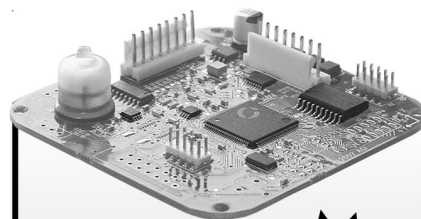
$$\int_0^\infty \alpha \nu^3 e^{-\beta \nu/T} d\nu / \int_0^\infty \frac{N}{R\beta \nu} \alpha \nu^3 e^{-\beta \nu/T} d\nu = 3 \frac{R}{N} T = 3kT$$

Wilhelm Wien found his distribution using the analogy to the Maxwell-Boltzmann distribution, although it did not occur to him to ask why that particle analogy might be valid for radiation. The above result is what you would get if you replaced the classical kinetic energy by pc , which would be appropriate for a massless particle. Einstein never explained why he did this calculation or what its significance was.

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Proper performance prediction for ITER

In his letter in the February 2006 issue of PHYSICS TODAY (page 10), David



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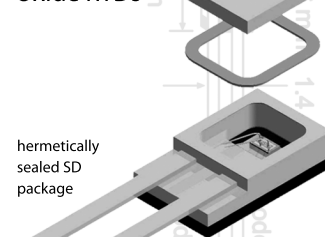
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