states accumulates the largest fraction of molecules.

The terms "enthalpy," "entropy," and "free energy" do not appear in the preceding outline, but they are present as weighted summations over the distribution functions.

Whether we use the language of thermodynamics or of statistical mechanics, we are concerned with huge assemblies of atoms and molecules. It is highly misleading to discuss the properties of a single molecule, large or small, in terms of changes in its free energy or chemical potential. Analysis of what happens to a long protein molecule under stress is properly treated in terms suitable for a mechanical model.

With that criticism aired, I applaud the authors for an otherwise fine article.

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Nelson, Powers, and Goldstein reply: We agree with Simon Bauer's points, and we regret if we inadvertently implied anything to the contrary. In fact, we believe that the rise of single-molecule biophysics demands more than ever that we present a statistical-mechanical viewpoint of the concepts of entropy and free energy.

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Gap in Einstein's Early Argument for Existence of Photons

During this the centennial year of Albert Einstein's epochal papers from his miraculous year, I was prompted to read again his paper on the quantum nature of radiation.[1] Surprisingly, I found a gap in his earliest argument for the existence of photons, a gap that apparently has remained unnoticed up to the present.

Einstein's argument was based on his proof that for sufficiently large frequencies the entropy of thermal radiation varies logarithmically with the volume, in the same manner it does in an ideal gas. He concluded that "monochromatic radiation of low density (within the range of validity of Wien's radiation formula) behaves thermodynamically as if it consisted of mutually independent quanta [photons] of magnitude $h\nu$,"[1] where ν is the frequency of the radiation and h is Planck's constant. In a footnote Einstein also gave a derivation, based on his entropy–volume relation, for the familiar pressure–volume formula of an ideal gas. But substituting in this formula Einstein's relation for the number of photons—that is, the energy of the monochromatic thermal radiation divided by $h\nu$—results in an incorrect expression for the pressure. This pressure is one-third of the energy density of the radiation, as was originally shown by Maxwell for the case of electromagnetic waves. Moreover, a kinetic-theory calculation of the pressure shows that this relation is also valid for photons.

Maxwell's relation also played a fundamental role in Boltzmann's derivation of the dependence of thermal radiation on the fourth power of the temperature, and in Wien's derivation of the general dependence of the thermal energy density on both frequency and temperature. I have not found any evidence, however,

that Einstein's contemporaries noticed the problem with calculating the pressure of monochromatic thermal radiation from Einstein's entropy–volume relation, nor has this problem been pointed out in commentaries about this paper.[2,3]

What is the solution to the pressure paradox? Einstein considered the volume dependence of the radiation entropy for fixed frequency ν, but in an actual thermodynamic process, where the volume V is changed by moving a piston, the frequency does not remain fixed, because the wavelength is proportional to the linear dimensions of the cavity. Hence, the frequency ν varies as $V^{-1/3}$, giving the entropy an additional volume dependence that was not discussed by Einstein. It can be readily verified that this addition leads to a thermodynamic derivation of Maxwell's relation for the pressure of isotropic radiation, filling in a long-standing gap in Einstein's earliest thermodynamic argument for the existence of photons.

References

1. A. Einstein, *Ann. der Phys. (Leipzig)* **17**, 132 (1905); reproduced in *The Collected Papers of Albert Einstein*, vol. 2, J. Stachel, ed., Princeton U. Press, Princeton, NJ (1989), p. 150.
2. M. Klein, *The Natural Philosopher* **2**, 59 (1963).
3. J. Stachel, ed., *Einstein's Miraculous Year: Five Papers That Changed the Face of Physics*, Princeton U. Press, Princeton, NJ (1998), p. 177.

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Albert Einstein to Heinrich Zangger[1]

Translated and annotated by Bertram Schwarzschild

Einstein writes to his friend Zangger (1874–1957), professor of physiology at the University of Zurich, the day after he submits the final version of the general theory of relativity to the Royal Prussian Academy of Sciences. While Einstein speaks of the theory's "incomparable beauty," his judgments of people are dark. He complains bitterly of his separated wife's malign influence on their children and of what he takes to be David Hilbert's plagiarism.

Berlin, 26 November 1915

Dear friend Zangger,

I'm sorry to hear that you're laid up and in pain. But I didn't understand the Latin name of the cause. Please tell it to me in German, or—still better—tell me that you're fully recovered.

. . . The general theory of relativity is finally completed. It wonderfully explains the rotation of Mercury's perihelion. From observation, astronomers have found that the planet's orbit rotates 45 ± 5 arcseconds per century. And from the theory, I get 43 arcseconds. Added to the line shifts of stellar spectra,[2] that's a rather good confirmation of the theory. For the bending of light by stars, the theory now predicts twice the deviation I previously derived [see PHYSICS TODAY, September 2005, page 14]. When we see each other, I'll tell you where that comes from.

The theory is of incomparable beauty. But only *one* colleague has really understood it, and he is trying, rather skillfully, to "nostrify" [*nostrifizieren*] it.[3] That's [Max] Abraham's coinage [from the Latin for "to make ours"]. In my personal experience, I've hardly come to know the wretchedness [*Jämmerlichkeit*] of humanity better than in connection with this theory.

My son [11-year-old Hans Albert] still hasn't answered my inquiry about meeting in Krummenau [in the Swiss Alps]. That's surely the influence of the woman [Einstein's wife Mileva]. You'll see, more and more, on which side goodwill and honesty are to be found. There are reasons that I couldn't abide staying with that woman, despite the tender love that binds me to my children. When we first separated, the thought of my children stabbed me like a dagger every morning when I woke up. Nonetheless, I never regret having taken the step. . . .

Affectionate greetings from your

Einstein

A week before this letter was written, Hilbert had presented a paper incorporating Einstein's theory into an attempt at a unified theory of gravity and electromagnetism.[3] Aside from complaining about Hilbert's improper appropriation of his work, in a 1916 letter to Hermann Weyl, Einstein criticized the physical assumptions Hilbert had added to the theory as being "childish, in the sense of a child that doesn't know the tricks of the outside world."[4]

References

1. *The Collected Papers of Albert Einstein*, vol. 8, R. Schulmann, A. J. Fox, M. Janssen, J. Illy, eds., Princeton U. Press, Princeton, NJ (1998), p. 204.
2. Einstein is referring to Erwin Freundlich's spectral measurements that seem to confirm the gravitational redshift predicted by general relativity. Later Einstein saw these results as only a qualitative verification. See ref. 1, p. 94.
3. See ref. 1, p. 195; L. Corry, *David Hilbert and the Axiomatization of Physics (1898–1918)*, Kluwer, Boston (2004), p. 287; A. Pais, *'Subtle Is the Lord . . .': The Science and the Life of Albert Einstein*, Oxford U. Press, New York (1982) p. 257.
4. Ref. 1, p. 278.

Feynman Stamp Is Dedicated

On 11 May, Richard Feynman's birthday, I had the privilege of attending the ceremony dedicating a stamp in his honor at the Far Rockaway Post Office in Queens, New York (see PHYSICS TODAY, May 2005, page 30). Among the attendees were his son, Carl; daughter, Michelle; and many other Feynman relatives. Directly after the ceremony, one corner of Cornaga Avenue in Far Rockaway, a street on which he had lived, was named "Richard Feynman Way."

The Feynman diagrams on the stamp show how Feynman's work that was originally applicable to quantum electrodynamics, and for which he won the Nobel Prize, was later used to elucidate the electroweak force. This force is illustrated on the stamp by vertex diagrams for the flavor-changing quark transitions emitting the $W^{\pm}$ boson, and flavor-conserving quark transitions emitting the Z^0, where $W^{\pm}$ and Z^0 represent respectively the charged and neutral intermediate vector bosons mediating the force.

Feynman's letters have recently been published in a widely respected book edited and annotated by Michelle Feynman.[1] Besides corresponding with physicists, he also answered letters from people from all walks of life. While in high school, according to the book, he taught himself "gamma functions, elliptic functions and differentiating under an integral sign." So it should be no surprise that as an undergraduate at MIT, Feynman was one of five national winners of the Putnam mathematics competition.

On the cover of a book written by