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In Search of Beauty

> What I remember most clearly was that when I put down a suggestion that seemed to me cogent and reasonable, Einstein did not in the least contest this, but he only said, "Oh, how ugly." As soon as an equation seemed to him to be ugly, he really rather lost interest in it and could not understand why somebody else was willing to spend much time on it. He was quite convinced that beauty was a guiding principle in the search for important results in theoretical physics.
> —H. Bondi

BEAUTY BEFORE TRUTH

My colleagues and I in fundamental physics are the intellectual descendants of Albert Einstein; we like to think that we too search for beauty. Some physics equations are so ugly that we cannot bear to look at them, let alone write them down. Certainly, the Ultimate Designer would use only beautiful equations in designing the universe! we proclaim. When presented with two alternative equations purporting to describe Nature, we always choose the one that appeals to our aesthetic sense. "Let us worry about beauty first, and truth will take care of itself!" Such is the rallying cry of fundamental physicists.

The reader may perhaps think of physics as a precise and predictive science and not as a subject fit for aesthetic contemplation. But, in fact, aesthetics has become a driving force in contemporary physics. Physicists have discovered something of wonder: Nature, at the fundamental level, is beautifully designed. It is this sense of wonder that I wish to share with you.

TRAINING OUR EYES

What is beauty? Philosophers pondering the meaning of aesthetics have produced weighty tomes, but an absolute definition of

aesthetic values remains elusive. For one thing, fashion changes. The well-endowed ladies of Rubens no longer grace magazine covers. Aesthetic perceptions differ from culture to culture. Different conventions govern landscape painting in the East and West. The architectural designs of Bramante and I. M. Pei are beautiful in different ways. If there is no objective standard of beauty in the world of human creations, what system of aesthetics are we to use in speaking of the beauty of Nature? How are we to judge Nature's design?

In this book, I wish to explain how the aesthetic imperatives of contemporary physics make up a system of aesthetics that can be rigorously formulated. As my art history professors used to say, one has "to train one's eyes." To the architectural cognoscenti, the same principles that guide the Renaissance architect guide the postmodern. Likewise, physicists have to train their inner eye to see the universal principles guiding Nature's design.

INTRINSIC VERSUS EXTRINSIC BEAUTY

When I find a chambered nautilus at the seashore (or more likely in a shellshop), its beauty captivates me. But a developmental biologist would tell me that the perfect spiral is merely a consequence of unequal rate of shell growth. As a human being, I am no less enthralled by the beautiful nautilus knowing this fact, but as a physicist, I am driven to go beyond the extrinsic beauty that we can see. I want to discuss the beauty of neither the crashing wave nor the rainbow arcing across the sky, but the more profound beauty embodied in the physical laws that ultimately govern the behavior of water in its various forms.

LIVING IN A DESIGNER UNIVERSE

Physicists from Einstein on have been awed by the profound fact that, as we examine Nature on deeper and deeper levels, She appears ever more beautiful. Why should that be? We could have found ourselves living in an intrinsically ugly universe, a "chaotic world," as Einstein put it, "in no way graspable through thinking."

Musing along these lines often awakens feelings in physi-

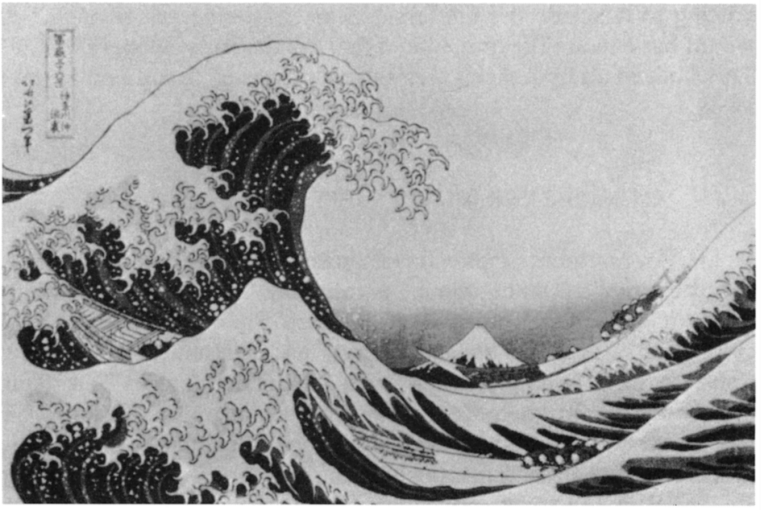

Figure 1.1. *(Top)* Hokusai (1760–1849) "Mount Fuji Seen from Kanagawa." *(Courtesy Minneapolis Institute of Art)*
(Bottom) Microphotograph of a snowflake *(R. B. Hoit, courtesy Photo Researchers, Inc.)*
The beauty of water on two different levels.

cists best described as religious. In judging a physical theory purporting to describe the universe, Einstein would ask himself if he would have made the universe in that particular way, were he God. This faith in an underlying design has sustained fundamental physicists.

THE MUSIC VERSUS THE LIBRETTO

Popularizers of physics often regale us with descriptions of specific physical phenomena, astounding their readers with the fantastic discoveries of modern physics. I am more interested in conveying a sense of the intellectual and aesthetic framework of contemporary fundamental physics. Consider opera. The aficionado likes *Turandot*, but not primarily because of its libretto. The absurd story takes flight because of Puccini's music. On the other hand, it would be difficult to sit through an opera without knowing the story or worse yet, to listen only to the orchestral part. The music and libretto inform each other.

Similarly, to speak of the multitude of specific physical phenomena (the libretto) without placing them in the aesthetic framework of contemporary physics (the music) is boring and not particularly enlightening. I intend to give the reader the music of modern physics—the aesthetic imperatives that guide physicists. But just as an opera with the vocal part taken out would be senseless, a discussion of aesthetics without reference to actual physical phenomena is sterile. I will have to go through the libretto of physics. Ultimately, however, both as a fundamental physicist and as an opera lover, I must confess that my heart lies more with the music, and not the libretto.

LOCAL ORDINANCES VERSUS CONSTITUTIONAL PRINCIPLES

In a book about physics, the much-abused phrase "physical law" is certain to be bandied about. In civil law, one distinguishes between local ordinances and constitutional principles. So too in physics, there are laws and there are laws. Consider Hooke's law, stating that the force required to stretch a metal spring is proportional to the amount by which that spring is stretched. It is an

example of a phenomenological law, a concise statement of an empirically observed regularity. In the 1930s, the theory of metals was worked out, and Hooke's law was explained in terms of the electromagnetic interaction between the atoms in a metal. Hooke's law addresses one specific phenomenon. In contrast, an understanding of fundamental laws governing electromagnetism enables us to explain a bewildering variety of phenomena.

When I was learning about such things as Hooke's law in high school, I got the impression that physicists try to find as many laws as possible, to explain every single phenomenon observed in the physical world. In fact, my colleagues and I in fundamental physics are working toward having as few laws as possible. The ambition of fundamental physics is to replace the multitude of phenomenological laws with a single fundamental law, so as to arrive at a unified description of Nature. This drive toward unity is *Fearful Symmetry*'s central theme.