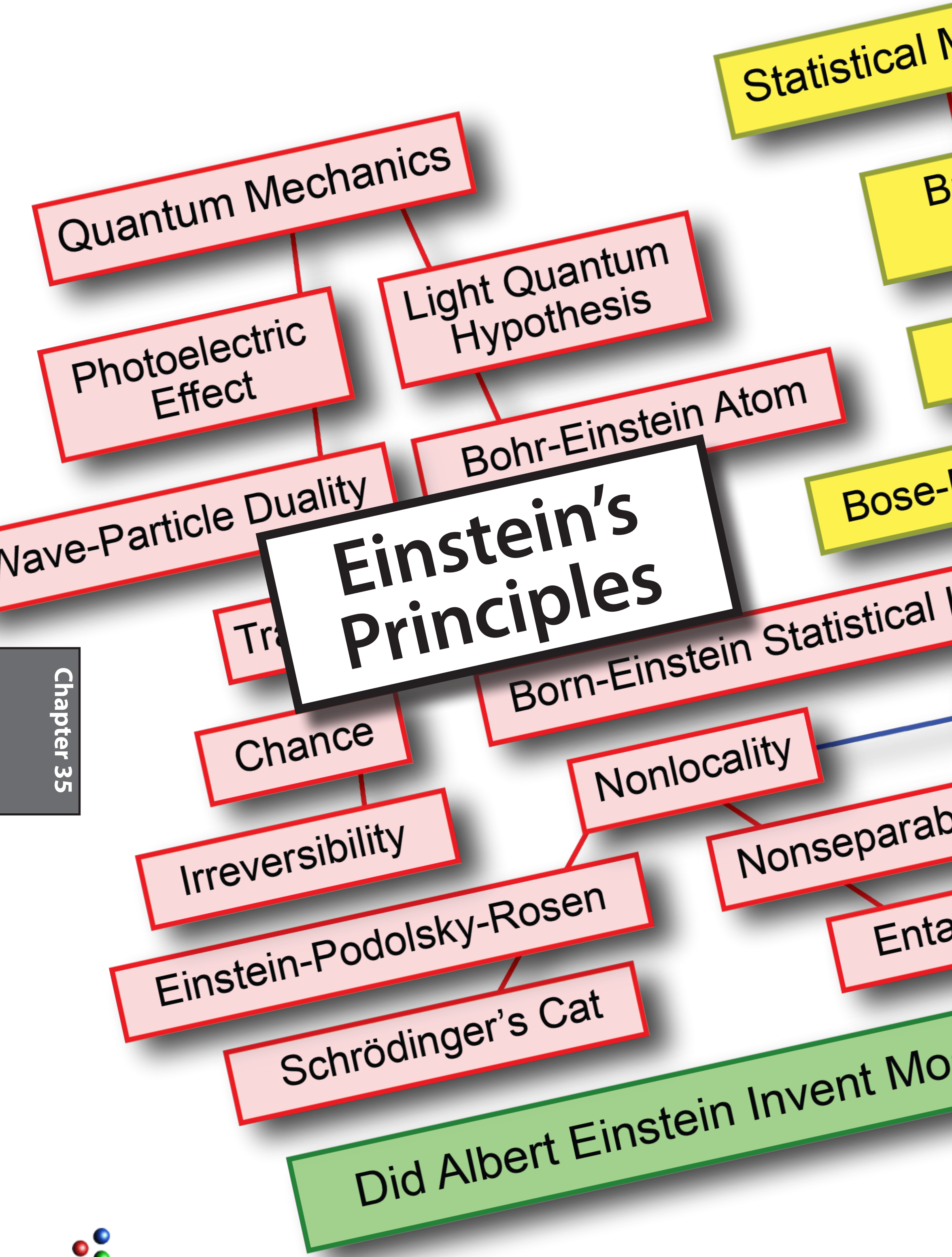
Statistical
Quantum Mechanics
Light Quantum Hypothesis
Photoelectric Effect
Bohr-Einstein Atom
Wave-Particle Duality
Einstein's Principles
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Born-Einstein Statistical
Chance
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Einstein's Principles

While the young Albert Einstein learned a great deal from Ernst Mach's notion that theories are "economic summaries of experience,“ in his later years he attacked theories that were simply designed to fit the available facts. Einstein challenged the idea that induction from a number of examples can lead to fundamental theories.

Positivists and empiricists declared that any theory not built from sense data about our experiences was mere *metaphysics*.

Einstein disagreed. The best theories should be based on "principles," he argued, perhaps biased by the astonishing success of his 1905 principle of relativity and 1916 equivalence principle?

Special relativity dazzled the world with its predictions that measured lengths of an object depend on the observer's speed relative to the object, and that events separated in space can have their time order reversed depending on the speed of the observer.

When all Einstein's amazing predictions were confirmed by experiment, many rushed to the subjectivist conclusion that everything is relative to one's point of view. But Einstein saw a deeper and *absolute* version of his principle, namely that the speed of light is an *invariant*, independent of the speed of the observer.

His theory of general relativity was based on his equivalence principle, that no experiment can distinguish between gravity and an accelerating force.

Einstein in no way denied the critical importance of experience, especially the experiments that test the validity of any theory and the principles it is based upon.

But here Einstein parted ways with physicists who believe that their theories, having been grounded in worldly experience, must actually *exist* in the real world. He startled many philosophers of science by declaring theories to be fictions, *inventions* by thinkers and not *discoveries* about the material contents of the universe.

Inspired by the great nineteenth-century mathematician Richard Dedekind, Einstein often described theories and their underlying principles as "free creations of the human mind."

A contemporary of Dedekind, Leopold Kronecker, had made the powerful claim that "God made the integers, all else is the work of man." Einstein may have felt that even the integers were created by human beings.

Einstein described his ideas about theories based on principles in 1919, shortly after his great success with general relativity, and long before the work of the so-called "founders" of quantum mechanics.

> There are several kinds of theory in physics. Most of them are constructive. These attempt to build a picture of complex phenomena out of some relatively simple proposition. The kinetic theory of gases, for instance, attempts to refer to molecular movement the mechanical thermal, and diffusional properties of gases. When we say that we understand a group of natural phenomena, we mean that we have found a constructive theory which embraces them.
>
> But in addition to this most weighty group of theories, there is another group consisting of what I call theories of principle. These employ the analytic, not the synthetic method. Their starting-point and foundation are not hypothetical constituents, but empirically observed general properties of phenomena, principles from which mathematical formula are deduced of such a kind that they apply to every case which presents itself. Thermodynamics, for instance, starting from the fact that perpetual motion never occurs in ordinary experience, attempts to deduce from this, by analytic processes, a theory which will apply in every case. The merit of constructive theories is their comprehensiveness, adaptability, and clarity, that of the theories of principle, their logical perfection, and the security of their foundation...
>
> Since the time of the ancient Greeks it has been well known that in describing the motion of a body we must refer to another body. The motion of a railway train is described with reference to the ground, of a planet with reference to the total assemblage of visible fixed stars. In physics the bodies to which motions are spatially referred are termed systems of coordinates. The laws of mechanics of Galileo and Newton can be formulated only by using a system of coordinates. [1]

1 *Science*, 51 (No. 1305); January 2, 1920; originally published in *The Times* (London), 28 November 1919, pp. 13–14.

What were Einstein's Principles?

Some of his principles were held by many earlier thinkers, such as the law of parsimony or simplicity, also known as Occam's Razor, that the simplest theory that fits all the known facts is the best theory. He may have liked the idea that the most true theories would be beautiful in some sense, for example their symmetry.

Others of Einstein's principles were the accepted laws of classical physics and chemistry. They were postulated relations between physical quantities that proved correct in experimental tests.

They include Newton's three laws of motion, his law of universal gravitation, Maxwell's and Faraday's laws of electromagnetism, and the four laws of thermodynamics. Einstein would have accepted Kirchhoff's Law that the spectrum of blackbody radiation does not depend on the material that is radiating. He himself proved the Stefan-Boltzmann law that radiated energy is proportional to the fourth power of the temperature *T*.

Now the first law of thermodynamics is also a *conservation* principle, specifically the conservation of energy. It was not fully understood until motion energy was seen to be converted into heat by frictional forces in the early nineteenth century. The conservation of other quantities like linear and angular momentum had been understood from motions of the planets, which show no obvious frictional forces. Einstein mentioned the lack of perpetual motion machines, which embodies the conservation of energy.

As we mentioned in the introduction, the great mathematician Emmy Noether stated a theorem that each of these conservation principles is the result of a symmetry property of a physical system.

Laws of physics are thought be independent of time and place. That they are independent of the time results in the conservation of energy. Independence of place leads to the conservation of momentum. Independence of angle or direction produces the conservation of angular momentum.

These great symmetries and conservation laws are sometimes described as *cosmological* principles. At the grandest universe scale, there is no preferred direction in space. The ultimate reference "to which motions are spatially referred" is most often the center of mass of nearby material objects, or as Mach expected, the entire matter in the universe, not an *immaterial* "system of coordinates."

The average density of galaxies appears the same in all directions, and the remote cosmic microwave background of radiation shows no asymmetries. There was thought to be no preferred time until the twentieth-century discovery of the Big Bang.

We shall see that Einstein did not fully apply these conservation principles in his work on the *nonlocal* behaviors shown by entangled particles. And despite being quite familiar with Noether's work, we have seen that he abandoned fundamental symmetry principles in his 1935 analysis of the Einstein-Podolsky-Rosen Paradox.[2]

One great principle that every physicist accepted in the early twentieth century was *causality*, the simple idea that every effect has a cause. Causality in turn implies that identical causes will produce identical effects, leading to the physical and philosophical idea of determinism.

Determinism is the idea that there is but one possible future, because all the events at any moment are the complete causes of the immediately following events and those events the immediate causes of the next events. The only possibilities are those that actually occur. Until he became convinced of the statistical nature of quantum mechanics in the late 1920's, Einstein was a determinist.

Some work that Einstein saw as lacking principles were attempts to fit equations to observed data, like Wien's distribution and displacement laws, and Planck's radiation law.

Einstein may have elevated the *continuum* to a principle, though 1) he was instrumental in disproving the hypothesis of an ether as the medium for electromagnetism, and 2) his work on Brownian motion established the atomic hypothesis which disproved the idea of continuous matter, just as his light quantum hypothesis disproved continuous energy.

In any case Einstein knew that all principles, and the laws of physics based on them, began as ideas, free creations of the human mind, and they only acquired their status as laws when confirmed by repeated experiments.

2 See chapter 26.

The Absolute Principles of Physics

Some of the *absolute* principles in physics are the conservation laws for mass/energy, momentum, angular momentum, and electron spin. The constant velocity of light is another.

Emmy Noether's theorem says these conservation principles are the consequence of deep *symmetry* principles of nature. She said for any property of a physical system that is symmetric, there is a corresponding conservation law.

Noether's theorem allows physicists to gain powerful insights into any general theory in physics, by just analyzing the various transformations that would make the form of the laws involved *invariant*.

For example, if a physical system is symmetric under rotations, its angular momentum is conserved. If it is symmetric in space, its momentum is conserved. If it is symmetric in time, its energy is conserved. Now locally there is time symmetry, but cosmically the expansion of the universe gives us an *arrow of time* connected to the increase of entropy and the second law of thermodynamics.

The conservation of energy was the *first law* of thermodynamics.

The famous *second law* says entropy rises to a maximum at thermal equilibrium. It was thought by many scientists, especially Max Planck, to be an *absolute* law. But as we saw in chapter 3, James Clerk Maxwell and Ludwig Boltzmann considered it a *statistical* law.

Einstein called Boltzmann's expression for the entropy "Boltzmann's Principle." $S = k \log W$. At the 1911 Solvay Conference, Einstein wrote,'

> the question arises, on the validity of which general principles of physics we may hope to rely in the field of concern to us. In the first place we are all agreed that we should retain the energy principle.
>
> A second prnciple to the validity of which, in my opinion, we absolutely have to adhere is Boltzmann's definition of entropy by means of probability.[3]

3 Stachel, 2002, p.375