CHAPTER 1

Prologue: A World in Crisis

WHEN, AT THE STROKE of midnight on December 31, 1900, the nineteenth century turned into the twentieth, the world was in a state of upheaval. Queen Victoria, until then the longest-serving British monarch in the Empire's history, had just twenty-two more days to live. Barely nine months into the new century President William McKinley was assassinated, being succeeded by Theodore Roosevelt. The Boer War between the Dutch and British was in its second year and would last for another, affording Winston Churchill his first appearance on the world stage. In the Far East, the Philippines revolted against the United States, and the Boxer Rebellion of Chinese nationalists against foreign imperialism had just begun.

In the more benign arena of the intellectual world, groundbreaking events were happening too: the year 1900 saw the publication of Sigmund Freud's first influential work, *The Interpretation of Dreams*, and the Vienna premiere of Gustav Mahler's First Symphony, *the Titan*, conducted by the composer himself. Pablo Picasso entered his "Blue Period" (1901–1904), and Max Planck introduced a new concept into physics that would soon revolutionize all of science: the quantum of energy. If all that weren't enough, David Hilbert, Germany's foremost mathematician at the turn of the century, challenged the Second International Congress of Mathematicians, held in Paris in 1900, with a list of twenty-three unsolved problems whose solutions he regarded as of utmost importance to the future growth of mathematics—as indeed they would prove to be.

Planck's introduction of the quantum into physics was followed five years later by Albert Einstein's publication of his special theory of relativity; together, they would mark the end of classical physics that had ruled science since the discoveries of Galileo Galilei three centuries earlier. But the transition from the old world to the new did not go smoothly; on the contrary, it subjected physics to its deepest crisis since the sixteenth and seventeenth centuries, when Nicolaus Copernicus, Johannes Kepler, and Galileo Galilei had overthrown the old Greek picture of the universe.

In a remarkable confluence of events, the crisis in physics in the closing years of the nineteenth century was mirrored in an equally deep crisis in another discipline of the human mind: classical music. Oddly, both revolved around a common theme—the choice of an appropriate frame of reference in which the physical universe and the universe of music should be set. Since these parallel developments provide the background for much of the later chapters in this book, I will elaborate here a little on the events that have led to them.

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In his monumental work *The Principia* (1687), Isaac Newton laid the foundations of dynamics on which scientists would base their work for the next 218 years. His mechanistic world picture, in which everything was in a perpetual state of motion governed by the force of gravity, became known as the "clockwork universe." Every physical phenomenon—from the behavior of atoms to the motion of the celestial bodies—was ruled by a set of precise, deterministic laws: specifically, Newton's three laws of motion and his universal law of gravitation. Later these laws would be formulated in terms of a set of differential equations that could be solved, at least in principle, provided that the initial state of the system—the position and velocity of each of its components—was known at some given time, conveniently designated as $t = 0$. Carried to its extreme, this mechanistic picture could be extended to the entire universe: if we only knew the position and velocity of each single atom at the moment of Creation, the future course of the universe would be determined for all time. This view, espoused by French mathematician Pierre Simon, Marquis de Laplace, would dominate scientific thought for nearly two centuries following Newton's death in 1727.

Hidden in Newton's grand scheme was an assumption that had always been taken for granted and thus rarely given much thought: the existence of a universal frame of reference, a kind of invisible coordinate system to which the position and motion of every particle in the universe could be referred. For practical purposes, this universal frame of reference was taken to be the system of fixed stars, whose position in the celestial dome seemed to have been unchanged over many generations (although Edmond Halley in 1718 showed that these stars have their own motion and were thus anything but fixed). The fixed stars were thought to belong to our own galaxy—the Milky Way—which was therefore given the role of a reference system at absolute rest, a rock-solid anchor to which everything else could be referred.

That this assumption was questionable didn't escape an occasional scrutinizing eye—least of all that of Newton, who was not entirely at ease with it. Already half a century earlier Galileo had realized that motion, by its very nature, is relative. As an example he gave the case of two ships sailing in calm waters far away from land. The passengers of either ship would find it impossible to tell which ship was stationary and which was moving, theirs or the other ship. This became known as the *Galilean principle of relativity*, and Newton, who was thoroughly familiar with Galileo's work, was fully aware of it. Yet the question of who is "really" moving and who is at rest was ignored by nearly all scientists up to the closing years of the nineteenth century. And if any proof was needed that the system was working just fine, it was amply provided by the spectacular triumphs of Newtonian mechanics, from the correct prediction of the return of Halley's Comet in 1758 to the discovery in 1846 of a new planet, Neptune, the eighth planet out from the Sun, by the sheer power of mathematics. It seemed that the clockwork universe was doing its work with unfailing mathematical precision.

But in the seventeenth century a new feature of the physical world was discovered: electricity. At first arousing mere curiosity in the form of static electricity—like the jolt you get when touching a metallic object on a cold, dry day—electricity soon became a phenomenon to be reckoned with. For example, an electric charge could travel along a metal wire and be transported from one place to another—an electric current. Even more surprising was the discovery that an electric current can deflect the needle of a magnetic compass; in other words, the current generates a magnetic field around the wire.

In the 1830s Michael Faraday, a self-taught English scientist, ran a series of experiments that firmly established the nature of electricity and its relation to magnetism. Faraday (1791–1867) was the experimental scientist par excellence: his world was the laboratory, where he tinkered with his gadgets, observed the outcome of his experiments, and drew his conclusions. But it took another British scientist to unify Faraday's findings into a coherent theoretical structure. That task befell the Scottish physicist James Clerk Maxwell (1831–1879). Maxwell formulated Faraday's experimental laws as a set of four differential equations that govern all electric and magnetic phenomena—henceforth to be called *electromagnetism*. At the core of Maxwell's theory was the concept of a *field*, a kind of invisible medium that carries electromagnetism through space as electromagnetic waves. Surprisingly, the speed of propagation of these waves turned out to be none other than the speed of light, 299,792 km/sec in vacuum. This number would be given the letter *c*, probably for the first letter of the Latin word for speed, *celeritas*.[1] It would become one of the most important numbers in physics.

Maxwell's equations, with their elegant internal symmetry, became the paradigm that theoretical physics strove to follow for the next hundred years, but they also made it clear that Newton's mechanistic world picture was no longer sufficient to explain the full range of the newly discovered phenomena. It seemed that physics comprised two distinct branches, each with its own laws. On one hand there was the mechanistic world, which also included heat and sound (the former because it is generated by the motion of molecules, the latter because it is the result of mechanical vibrations transmitted through the air as pressure waves). On the other was electromagnetism, which also included optics (because Maxwell's equations showed that light is an electromagnetic wave, having a particular frequency range that our eyes perceive as colors). The disparity between these two branches—foreshadowing the schism between relativity and quantum mechanics in the twentieth century—had to be bridged by some grand unifying theory.

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The fact that electromagnetic waves could propagate through empty space did not sit well with nineteenth-century physicists. Still deeply rooted in the Newtonian mechanistic world picture, they tried to invoke the seemingly analogous case of sound waves propagating through air. Here is a material medium that transmits the vibrations of, say, a violin string as pressure waves through space, in much the same way as ripples in a pond are propagated as surface waves on the water.[2] Clearly there must likewise exist some material medium permeating space through which electromagnetic waves are propagated. Thus was born the concept of the *ether* (also known as *luminiferous medium*); it would become a fixture of late nineteenth-century physics.

The ether was more than just a medium for propagating electromagnetic waves; it also served as a convenient cosmic reference system to which all motion could be referred. But this at once created a problem: if all motion is to be measured relative to the ether, then the speed of light, *as seen by an observer*, must depend on the observer's own speed relative to the ether. Specifically, if a source of light is moving toward a stationary observer at the speed v, the emitted light should reach the observer at the speed $c + v$, while if the source is receding from the observer, the perceived speed should be $c - v$. A similar effect should occur if the source is stationary and the observer is moving toward or away from it. In other words, the speed of light *as seen by the observer* depends on the observer's own speed and is therefore a variable quantity. And that was the crux of the crisis: Maxwell's equations do not require the presence of any material medium for the propagation of electromagnetic waves; the electromagnetic field itself is the medium. So the speed of light must be a universal constant, independent of the observer's motion relative to the source.

To settle the question once and for all, a famous experiment was conducted in 1887 at Case Western Reserve University outside Cleveland, Ohio, by two American physicists, Albert Abraham Michelson (1852–1931) and Edward Williams Morley (1838–1923). Their aim was to measure the speed of light relative to the Earth, the latter serving as a moving platform that travels through space at about 30 km/sec in its orbit around the Sun. If the ether exists, an observer on the Earth should perceive the speed of light to be $c + 30$ km/sec when moving toward a distant source of light, and $c - 30$ km/sec when moving away from it half a year later. The difference, though exceedingly small (Earth's speed is about 1/10,000 that of the speed of light), could still be detected by optical means. But despite several attempts to do just that, no difference whatsoever was detected. The speed of light was the same regardless of the direction of Earth's motion relative to the ether.

Various attempts were made to explain the negative results of the Michelson–Morley experiment, using all kinds of assumptions that were proposed only for this one purpose and thus lacking credibility. It befell Albert Einstein (1879–1955), then a twenty-six-year-old junior clerk at the Swiss Federal Patent Office in Bern, to give the correct explanation: *the ether does not exist—it is pure fiction*. Consequently, there is no single, universal frame of reference at absolute rest relative to which all motion can be referred. Abandoning the ether, however, came at a price, for if the speed of light should be the same in all frames of reference, then not only space, but also time must be relative. Absolute space and absolute time became things of the past. What's more, space and time ceased to exist as separate entities, to be replaced by a single, four-dimensional reality: *spacetime*.

Einstein published his *special theory of relativity* in 1905. It is called "special" because it applied only to the special case of frames of reference moving relative to one another at constant speed. Over the next ten years he tried mightily to extend the theory to *all* frames of reference, specifically to accelerating ones. He published his magnum opus, the *general theory of relativity*, in 1916, and it was at once hailed as the most elegant theory ever proposed in physics. General relativity replaced the Newtonian concept of gravitation as a force acting at a distance with a geometric interpretation, in which spacetime deviates from its flatness in the presence of mass; it becomes curved.

Among other things, the theory predicted that a beam of light would be deflected from its straight-line path in the presence of a heavy body such as the Sun. This was confirmed at the total solar eclipse of May 29, 1919, when a field of stars near the eclipsed Sun was photographed and compared with the same field several months later. The positions of the stars were carefully measured and found to deviate from their normal positions by just the amount predicted by Einstein. When the results were announced at a special joint meeting of the Royal Society and Royal Astronomical Society in London in November of that year, Einstein overnight became world famous.[3] As of today, general relativity has passed every experimental test to which it has been subjected.

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At the very same time that classical physics was struggling with the ether problem, classical music went through its own crisis. A century earlier, Franz Joseph Haydn (1732–1809) and Wolfgang Amadeus Mozart (1756–1791) set the stage by establishing the symphony as the centerpiece of classical music. But though their music was supremely beautiful, they wrote it chiefly for the aristocratic elite of Vienna, who wanted to enjoy a good evening of entertainment in the palaces of the rich and mighty. It befell Ludwig van Beethoven (1770–1827) to transform the symphony into a powerful emotional experience, capable of lifting the human spirit just as a great work of literature could—and he addressed it to the entire world. Haydn wrote 104 symphonies (actually 105, but one is lost), Mozart 41, and Beethoven just nine,[4] but what powerful works they were! His last, the Ninth (*Choral*) Symphony, first performed in 1824 and scored for a large orchestra, four vocal soloists and a choir, has become the icon of universal brotherhood—so much so that it was performed in 1989 in the shadow of the fallen Berlin Wall to mark the reunification of Germany.[5]

Beethoven died in 1827, exactly one hundred years after Newton. And just as with Newton, the ghost of Beethoven would loom over Western music for the next hundred years. Whether consciously or not, no major nineteenth-century composer dared to write more than nine symphonies (Franz Schubert wrote eight, Robert Schumann and Johannes Brahms four each, Hector Berlioz just one). The "curse of the ninth" so much gripped Gustav Mahler that (according to the account of his wife, Alma) he feared he would die if he attempted to write a tenth symphony—and indeed his foreboding came true: the work was left unfinished at his death in 1911. But while the symphonic output of individual composers declined, the orchestral forces calling for their performance steadily grew. Mahler's Eighth, the *Symphony of a Thousand* (1906), was scored for eight vocal soloists, a double choir, and a huge orchestra, a combined force that dwarfed even Beethoven's Ninth.

But it wasn't only the size of the orchestra or the emotional power of the symphonic genre that had expanded since Beethoven; the harmonic range of music underwent an even greater expansion. Before Beethoven, the choice of permissible chords available to a composer was quite limited; basically, it was confined to consonant or pleasing chords, such as the *major triad* C–E–G. This was a result of the chief role of pre-Beethovenian music: to please the listener. Whether in a public concert, in a royal reception, or in the solemn setting of the church, music was meant to entertain, or in the latter case, to arouse in the audience a sense of awe at God's creation. "Music, even in the most terrible situations, must never offend the ear" wrote Mozart in 1782. Even when a work was composed in a minor key, characterized by the somber-sounding *minor triad* C–E-flat–G (called minor because the interval C–E-flat is smaller than C–E by a half tone), the chords themselves were limited to consonances. An occasional dissonance might be inserted now and then, intended to create a momentary sense of tension or parody, but it was a brief distraction, to be "resolved" immediately to consonant chords again.

Beethoven changed all this. In his Third Symphony, the *Eroica*, first performed in public in 1805, he repeatedly used jarring dissonances and syncopations (off-the-beat stresses) with the explicit intention of shocking his listeners, and shock them he did: the symphony was sharply criticized for transgressing all accepted norms of "good" music. Beethoven, as always unperturbed by public criticism, stayed his course, and soon other composers followed suit: Berlioz (1803–1869) routinely used formerly "forbidden" chords to dramatize his music, and Richard Wagner and Mahler broke traditional limits even further. By midcentury the symphony had become a powerful emotional experience, capable of lifting the listener to the highest spheres of excitement, fervor, even fear. The story is told of Berlioz, the most romantic of the early Romantic composers, who, while attending a performance of a Beethoven symphony, was so overcome by emotion that he was visibly trembling. The person seated next to him turned to Berlioz, saying "Monsieur, why don't you go outside for a little break so you can come back and enjoy the music?" To which Berlioz answered in disgust, "Do you really think I came here to *enjoy* myself?"[6] The idea that music—and in particular symphonic music—must "never offend the ear" was a thing of the past.

With the abandonment of traditional harmonies came the abandonment of tonality. For three centuries, from about 1600 to 1900, the idea that a piece of music should be anchored to a basic key around which it evolves, and to which it ultimately returns, had been the very foundation of Western music. This *principle of tonality*, or key-based music, gave the piece a sense of direction, of purpose. Tonality was to classical music what the ether was to classical physics—a fixed frame of reference to which every note of the work was related.

But as the nineteenth century came to a close, this time-honored principle came under attack. Already in Berlioz's music, and much more so in Mahler's, the sense of tonality became increasingly vague, making it difficult to sense where one stood as the work progressed: music became ever more *atonal*. It was against this backdrop that Arnold Schoenberg—then still a relatively unknown Viennese composer and still using the German umlaut in his name—sensed that tonality had run its course. He resolved to devise a new system of composition which, he hoped, would put tonality to rest once and for all. To what extent his mission has succeeded we shall soon see.

NOTES

1. See the article "Why Is *c* the Symbol for the Speed of Light?" by Philip Gibbs (2004), at http://math.ucr.edu/home/baez/physics/Relativity/SpeedOfLight/c.html.
2. With one difference: in sound waves, the air molecules vibrate in the same direction as the wave itself (longitudinal waves), whereas surface waves propagate at right angles to the up-and-down motion of the water molecules (transverse waves).

3. The dramatic aftermath of this historic event has been described many times; see, for example, Ronald W. Clark, *Einstein: The Life and Times* (New York: Avon Books, 1971), pp. 263–264. In recent years some doubt has been cast on the validity of the eclipse results; see John Waller, *Einstein's Luck: The Truth Behind Some of the Greatest Scientific Discoveries* (Oxford: Oxford University Press, 2002), chap. 3.
4. Not counting the so-called *Battle Symphony* (also known as *Wellington's Victory*), a bombastic piece of musical trivia that, if anything, serves to show that even a great composer is capable of producing works of utter mediocrity. It enjoyed a huge success in Beethoven's time; today it is almost forgotten.
5. But also by the Berlin Philharmonic in 1942, with top Nazi officials attending, to boost the nation's morale after the defeat of the German Army at the Battle of Moscow.
6. Norman Lebrecht, *The Book of Musical Anecdotes* (New York: The Free Press, 1985), p. 118.