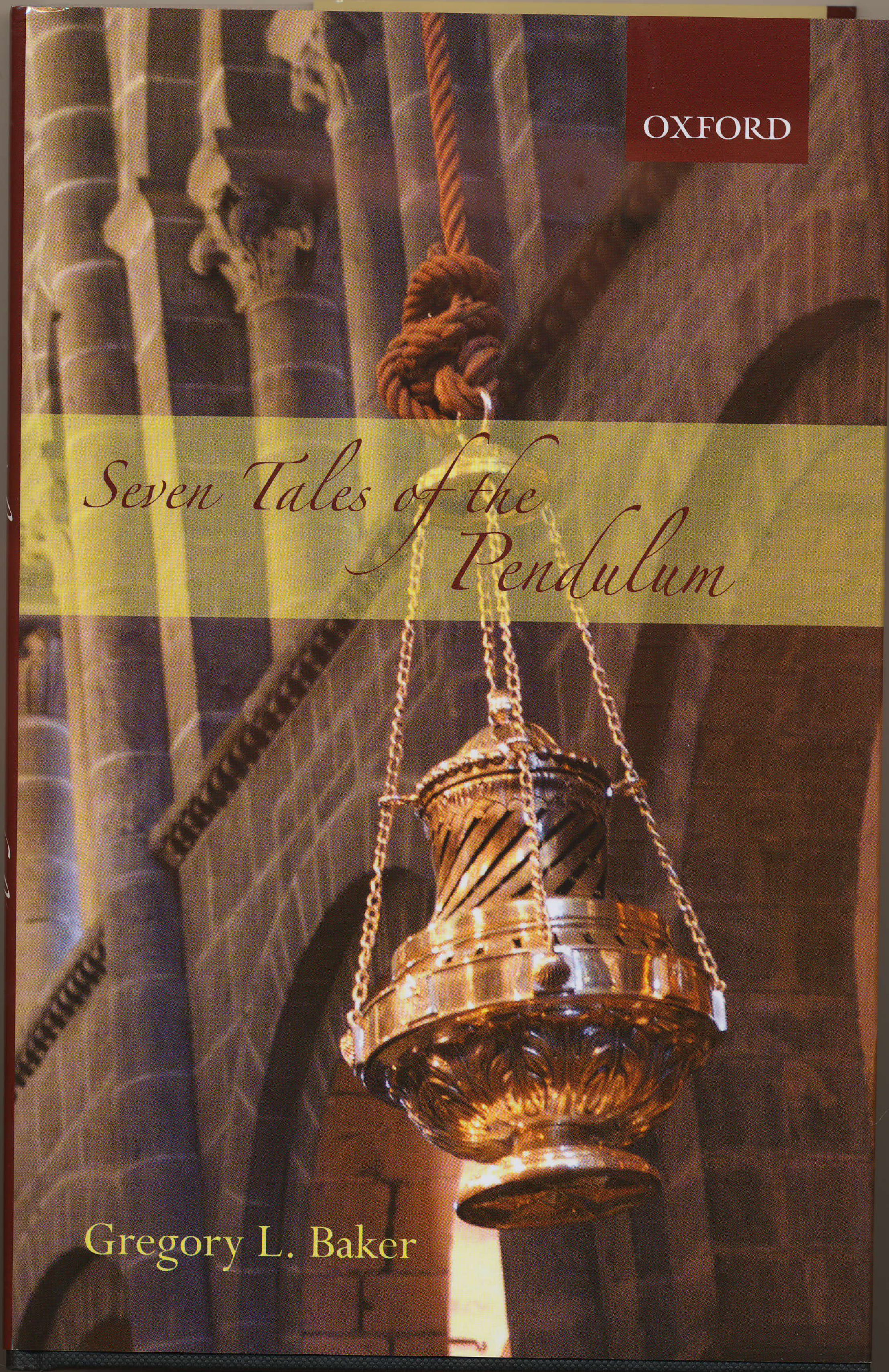
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Seven Tales of the Pendulum
Gregory L. Baker

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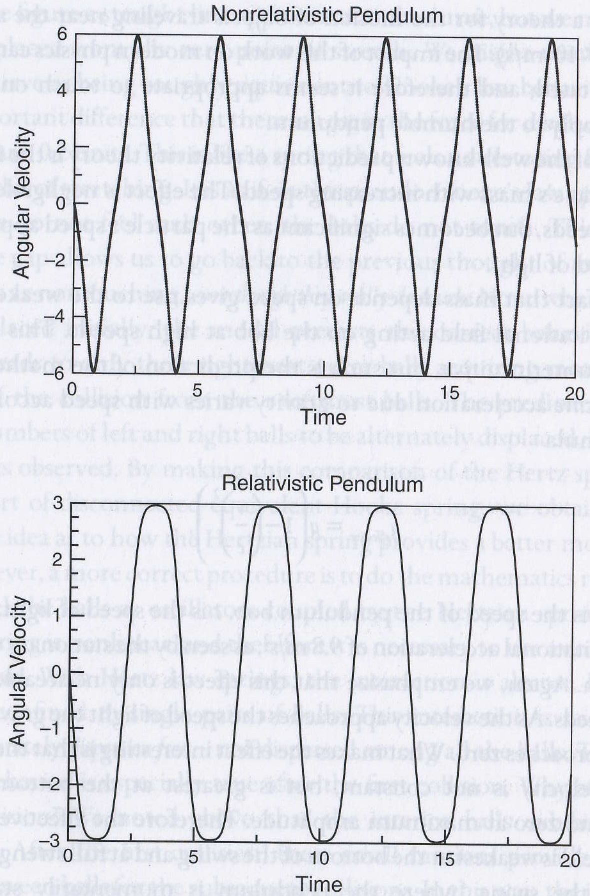

Figure C.7 Velocity time series for the nonrelativistic (upper) and relativistic pendulums (lower).

144 degrees above the downward vertical. This large amplitude helps us highlight the differences between the nonrelativistic and relativistic motion.

Note that for the relativistic case, the period is longer, as illustrated by there being only four upward peaks in the relativistic case compared to six peaks in the nonrelativistic case. Again, the cause for this increase is relativistic weakening of the restoring force of gravity as the pendulum bob goes through the downward vertical position. Furthermore,

the maximum velocity for the relativistic case is the speed of light used in this simulation. It is only about half of the maximum velocity for the nonrelativistic case. As the speed of light is approached, the effective gravitational field becomes negligible; the pendulum has little force acting on it to accelerate its motion as it nears the bottom. In comparing the two time series, we see a significant flattening of the velocity peaks in the relativistic case.

A typical macroscopic pendulum might have a velocity of a perhaps a meter per second. The molecular quantum pendulum we discussed earlier might have a velocity of several hundred meters per second. Relativistic speeds are actually commonplace on the quantum level in high-energy physics. But the creation of a macroscopic classical gravity pendulum that is relativistic seems far-fetched. Nevertheless, it is still intriguing to see what changes relativity theory brings to the motion of a simple pendulum.

C.4 The Long Now clock

The expression "a New York minute" is familiar to many as being a short time interval. One definition – allegedly due to a Texan – suggests that it is the nanosecond time interval between the moment the red light at your intersection turns green and the time when the New York driver behind you honks his horn to get you moving. This time interval might be called the "short now". It is suggestive of the rapid pace of modern life and the desire for instant gratification. Yet some people regret the loss of a more measured pace that values craftsmanship and care over mass production. Thus, the movement toward a "long now" was born. In the April 2, 2000 edition of the *New York Times*, an article appeared describing an extraordinary torsion pendulum clock, designed by Danny Hillis and funded by The Long Now Foundation (www.longnow.org). The accompanying photograph, reproduced here as Figure C.8, depicts the prototype of this startling design.

This version is 9 feet tall, but the plan is to build a full-scale version ten times larger and locate it in a remote desert environment in Nevada. It is intended to keep time for 10,000 years, a symbolic span comparable to the time that has elapsed since the end of the last ice age!

The clock is based on a torsion pendulum that oscillates once every 30 seconds. As in any clock, energy loss in the oscillator is made up

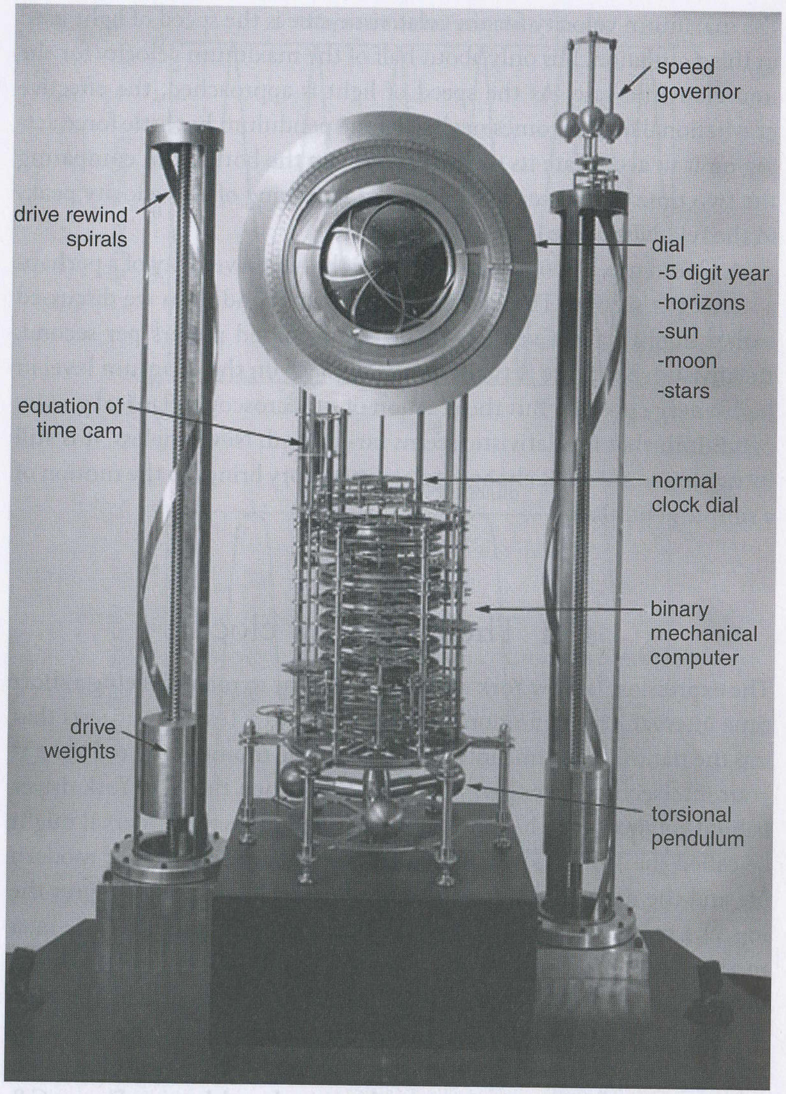

Figure C.8 An overall view of the Long Now clock. (Photo by Rolfe Horn, courtesy of the Long Now Foundation.)

through the action of an escapement, which is powered, in this design, by falling weights.

In the photograph of Figure C.9, the 22 pound triple mass tungsten pendulum can be seen below the first few layers in a stack of interacting gears. The full stack is visible in Figure C.8. This assembly is in fact an elaborate mechanical computer, designed to keep track of time through the millennia, accounting for such factors as the 26,000 year precession of the equinoxes. The evolving appearance of the night sky is calculated and displayed on the black sphere at the top of the clock.

The conception of this clock is not so much about timekeeping, but about the intersection of art and technology. Nowadays, very precise clocks are relatively inexpensive and very precise. Computers are equally

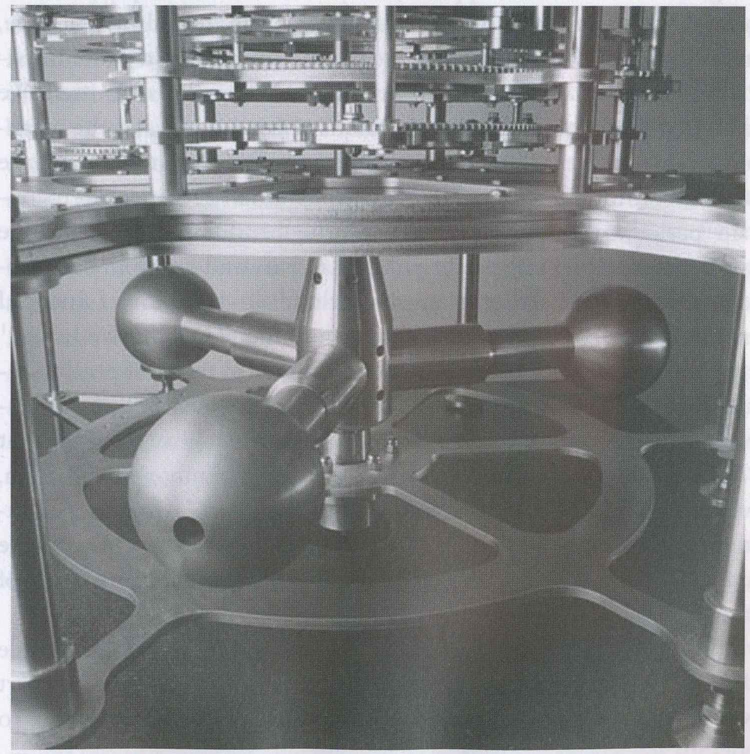

Figure C.9 A close-up view of the triple mass torsion pendulum that is the heart of the Long Now clock. (Photo by Rolfe Horn, courtesy of the Long Now Foundation.)

cheap and powerful. Therefore, a mechanical clock and a mechanical computer are seemingly a throwback to earlier epochs when individual invention and high craftsmanship were hallmarks of human ingenuity and creativity. Harrison's clocks and marine chronometer of the eighteenth century come to mind. The Long Now clock reasserts the value of the human component in technology while looking to the future in a wonderfully anachronistic way.

C.5 Some final thoughts

We have now completed a heavy immersion in the science and history of the pendulum, a seemingly simple system with a deceptively broad range of behaviors and applications. We find that the pendulum is sometimes surprising, sometimes even exciting, but always, I hope, interesting. Yet the dynamics of the pendulum may hold wider implications than just those of the effects of the physical system itself. We note that the mathematical descriptions of pendulums and the mathematical models that characterize some nonphysical systems may have certain common features. Time series of human activities often contain periodic motions like those of the pendulum; these include approximate cycles in periodic political activity and many kinds of biological rhythms. Further examples include the behavior of financial markets and the electrical neural activity of individual human brains.[1]

We might view society or even the individual in terms of pendulum-like behavior. Even common speech reflects this wider view. For example, when events or groups go well beyond normalcy, we often say that "the pendulum has swung too far". Or, after some minor perturbation, we might predict that the pendulum will "swing back". Does the pendulum become a metaphor for societal or individual behavior? Do people and groups sometimes act like pendulums? Is the pendulum an image of human activity?

A common characteristic held by both damped small-amplitude pendulums and human individuals or groups is the tendency to revert to some sort of equilibrium state. The pendulum with friction tends to

[1] Chaos in human brain waves has been associated with the ability of the human mind to quickly test a variety of solutions to immediate challenges, and nimbly come up with the most efficient answer.

return to the downward vertical position. After a small crisis or disturbance, individuals usually settle back into their typical behavior. Psychologists say that this tendency is due to an individual's "ego strength". We might then correlate the friction parameter of the pendulum with the corresponding ego strength of the individual. Groups and organizations also have ego strength, although perhaps we would more typically call it "inertia".

When the pendulum is strongly driven, as we saw in the tale of the chaotic pendulum, the pendulum undergoes transitions to new behaviors – sometimes chaotic, sometimes periodic. In a similar way, extreme circumstances may transform groups and individuals from placid equilibrium states. Natural disasters and wars can destroy or completely change a society. Simplistically, World War II transformed the form of the government in Japan from that of an imperial state to a democratic one. The 1930s change of Germany from a democratic state to a Nazi fascist dictatorship, and then back to a democracy in the postwar era, is another example from that turbulent period. In this latter example, we see a parallel with the bifurcating changes for a driven pendulum going from a state of periodic motion to chaotic motion, and then back to periodic motion. On a smaller scale, dramatic individual and group transformations occur in cults. Charismatic, destructive leaders can induce profound changes in the behavior of their followers. The 1978 mass suicide at Jonestown, Guyana illustrates the combined effects of brainwashing and intimidations in causing what was certainly the ultimate transformation of a group under pressure. Yet individuals from cults can also be transformed back to a more quiescent state through reprogramming efforts – a further bifurcation.

Thus we speculate that in ordinary daily life, groups and individuals exhibit behavior similar to the small-angle pendulum – small oscillations around some mean. But under extreme stress, human transformations are not unlike the bifurcations in pendulum behavior caused by strong forcing of the damped pendulum.

It is time to conclude our story. In the spirit of the pendulum-as-metaphor, it seems fitting to end with a 1657 quotation from the philosophy of the Czech cleric and teacher John Amos Comenius (1592–1670), sometimes considered the father of modern education. In what we now might regard as a quaint but still interesting view, Comenius saw the clock as a universal metaphor. He first associated the clock, with its movement of wheels and bells, with the structure and movement of the whole world. Then, through a kind of correspondence principle, he progressed from