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"The gold nugget of relativity books."
—*J. Gribbin, NEW SCIENTIST*

Lewis Carroll Epstein

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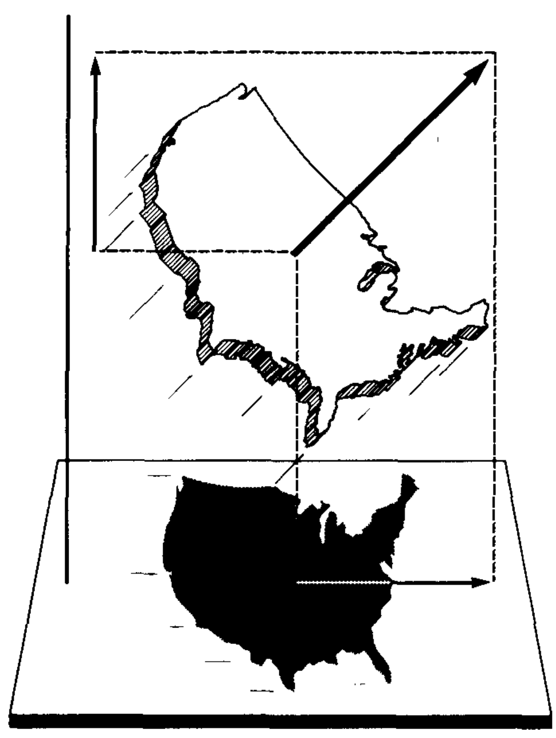

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Written and Illustrated by

Lewis Carroll Epstein

City College of San Francisco

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In Memory of My Father

HARRY EPSTEIN

Attorney at Law

3229 MISSION ST., AT VALENCIA

SAN FRANCISCO

The following people played important parts in putting this story together:

encouragement	**Michael Scott** **Robert Pisani**
education	**Michael Gardebled** **Jonathan Kern** **Louise Ainsworth** **Gerald Leone**
discussions of theory	**Harry Dart** **John Ehlers** **David Wall** **Robert Nason** **Peter Epstein** **Danny Epstein** **Renie Baus** **David Sonnabend**
word processing	**Margaret Oakley**
organizing	**Amy McManus**
initiation to the world of publication	**Robert Head** **Darlien Fife** **Paul Hewitt**
illustrations	**Ellen Buoncristiani**
editing, design, and production	**Robyn Brode**
typesetting	**Turnaround**
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Chapter 5 is the centerpiece of this work. The chapters preceding it relate to its development and those following it relate to application of its perspective.

Table of Contents

Chapter 3
Pandora's Box
Mostly about time desynchronization and its consequences

Chapter 4
Measuring the Consequences
Mostly about how to calculate the effect exactly

Chapter 5
The Myth
Mostly about why space shrinks, time slows, and why you can't go faster than light

Chapter 9

Enigma

Mostly about changing the speed of light

Chapter 10

Cause of Gravity

Mostly about how curved spacetime makes gravity

Chapter 11

Space Warped

Mostly about how curved space makes gravity

Chapter 12
The Ends of Space and Time

Mostly about the rupturing and mending of heaven

Appendices

Mostly about technical business

While most will sleep, a few will creep, in places deep, where dark things keep...

Among all creatures, humans are distinguished by the extent to which they wonder about things that do not immediately affect their subsistence.

Chapter 1

The Principle of Relativity

Galileo's Dictum

The year Columbus spent discovering the New World, a university sophomore named Copernicus spent discovering mathematics and astronomy. These discoveries and a lifetime of study led Copernicus to the realization that the earth was not only a globe in space, but that the globe MOVED around the sun.

However, most thinking people found it impossible to believe that the heavy earth could be in motion, indeed, in perpetual motion. They presented reasoned arguments against Copernicus's theory. Here is one such argument: Suppose the earth does move and suppose you drop a coin directly above your toe. By the time the coin falls to earth the earth will have moved and your foot will be carried with it. So the coin must miss your toe. But if you drop a coin above your toe it will, in fact, hit your toe. Thus the earth cannot be moving.

About a century later, while the

Figure 1–1. If the earth was moving, then dropped objects would not fall straight down.

first English colonies were being established in North America, Galileo came to the defense of the moving earth idea. Here, in a nutshell, is Galileo's counterargument. Suppose you are flying along smoothly and standing inside an aircraft cabin, even in a supersonic aircraft, and you drop a coin directly above your toe. Sure enough, it hits your toe.* Galileo referred to a ship's cabin rather than an aircraft cabin, but the central idea is that if you are closed inside a box that is moving smoothly, that is, not starting or stopping or jerking or turning but just moving at one speed in one direction, you **cannot** tell if you are in motion; **everything** in your box happens as if you were at rest. That fundamental idea became known as Galileo's Dictum.

Moreover, if you open a window in the box and look out and see another box approaching your box, you still can't tell if you are moving. You can't tell if you are moving toward the other box or if the other box is moving toward you. All you know is that there is **relative** motion between the boxes.

In essence, Galileo's Dictum is this: All smooth, linear motions are

Figure 1–2. But dropped objects do fall straight down. Therefore, the earth cannot be in motion.

*The coin hits your toe because if your toe is moving to the right due to the aircraft's motion, so also is the coin moving to the right at the moment it is dropped, since the coin is joined to the aircraft by your body just before you drop it. The coin keeps moving to the right after you let go. So the coin follows your toe and hits it.

relative. The universe is full of particles, all moving in different directions at different speeds. Who is to say which particle is really, absolutely, at rest? Thus you can never say, "The speed of this particle is 900 miles per hour." All you can say is, "The speed of this particle is 900 miles per hour relative to the air, or relative to the moon, or relative to this earthquake wave front." This is all very reasonable and the business would be permanently settled here were it not for certain curiosities about light first noted by a keen-eyed painter, Franciscus Grimaldi, who was officially employed by the very two popes with whom Galileo had his difficulties.

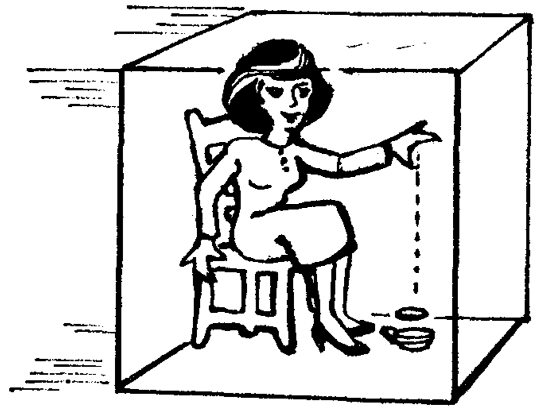

Figure 1–3. Smooth motion in a straight line does not affect what is happening inside the box. You might think that is obvious, yet in the day of Galileo it was a new idea.

Light

Grimaldi observed that surrounding and even inside the shadow of an opaque object were several rings or fringes. Now, most people had supposed that light was a rain of minute particles. That idea fit well into Galileo's scheme of a world of particles and it explained why light flies in straight lines and why shadows are exact silhouettes of the objects that cast them. But it did not explain Grimaldi's fringes.

The artist proposed that light was a fluidlike substance that could flow slightly around and behind objects, and that the fringes resulted from ripples spreading downstream from the edges of an object, just as ripples spread from the edges of a stone

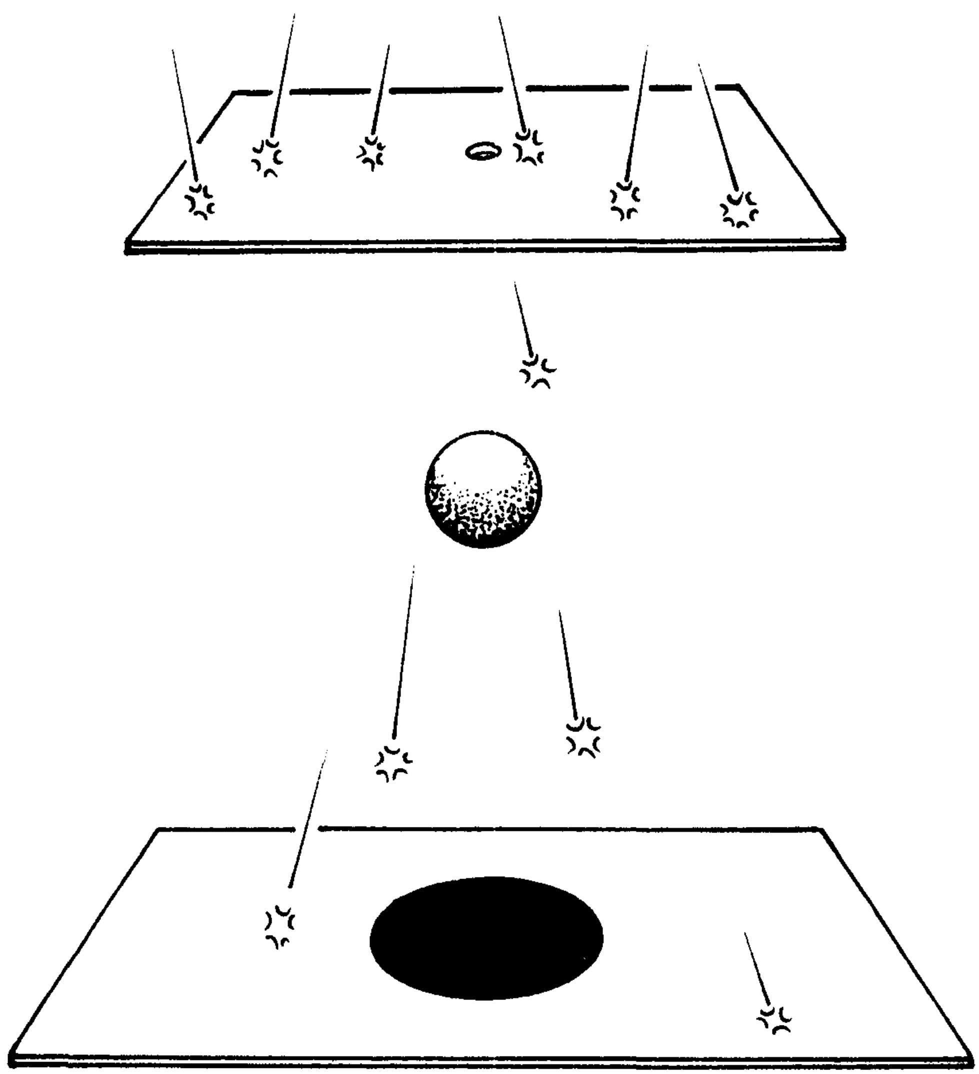

Figure 1–4. If light is a rain of little pellets, an object should completely shield the area behind it, as illustrated here. To do this experiment, you need a point source of light. The sun (or a light bulb) is not a point source. So the light is passed through a pinhole; the pinhole is the point.

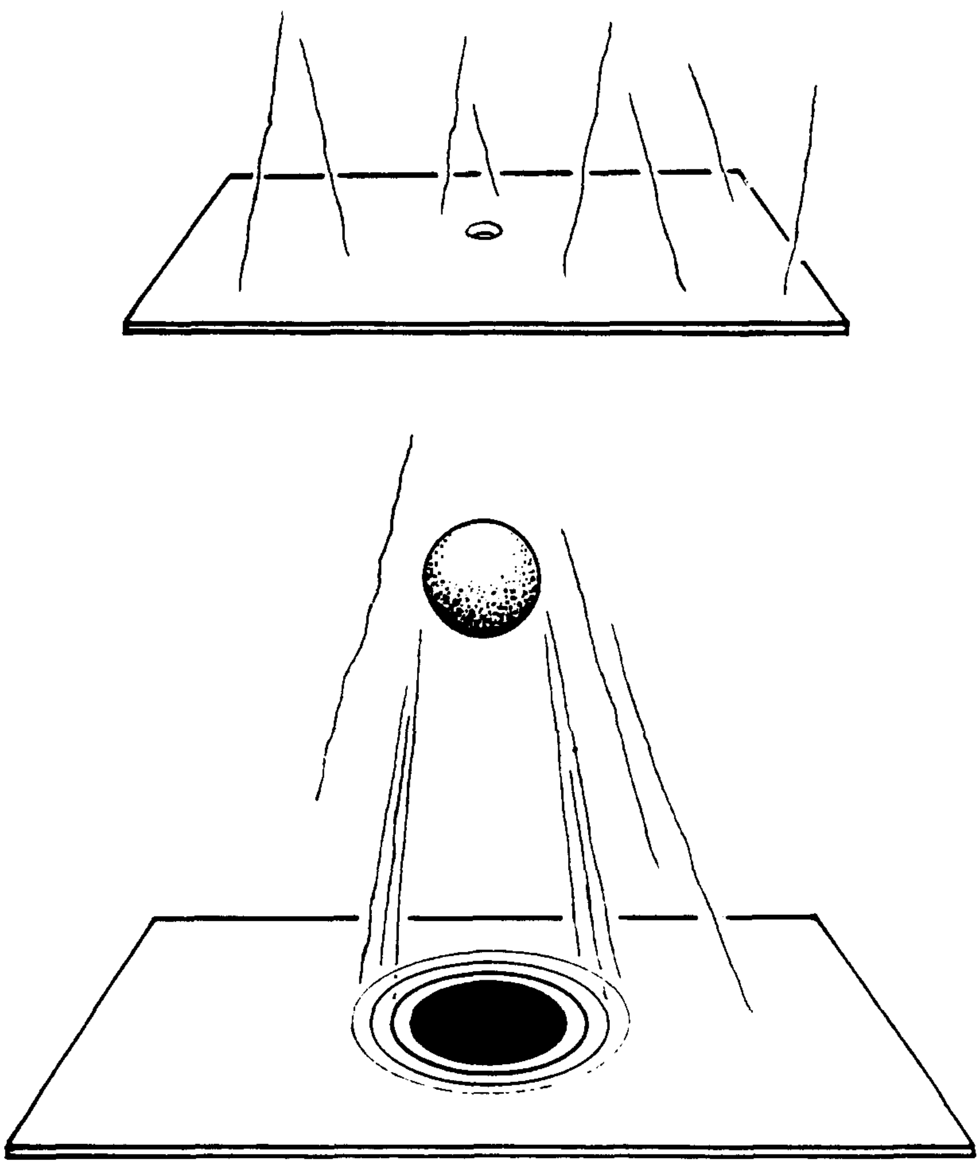

Figure 1–5. *But in fact, the area behind an object is not completely shielded. If you look very closely, you will see it is contaminated with rings of light.*

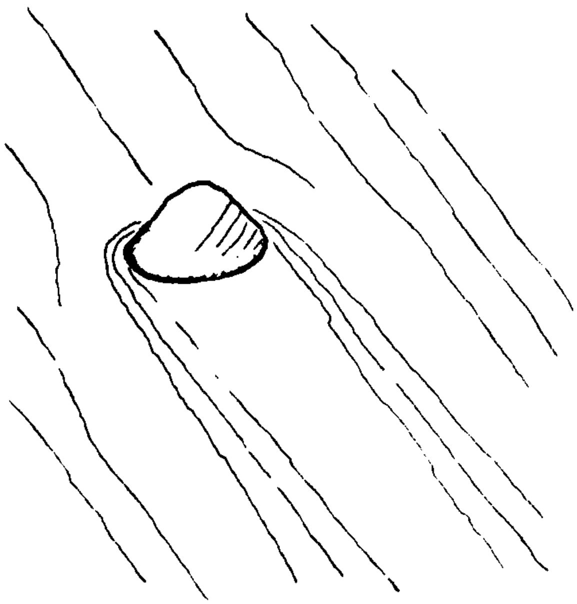

Figure 1-6. Note the waves spreading into the shielded area of quiet water behind the stone.

around which a fast current is flowing. In this way the wave nature of light first came to be suspected.

As the theory was subsequently developed, light was taken to be a vibration transmitted through space, rather than a fluid flow through space. (Yet, flow effects will return us to the mainstream of this story.) The great utility of the wave theory of light was that it showed why light can go around small things—waves spread—and why light sometimes does not appear where you expect it should—waves can cancel each other out.

The wave theory of light explained the halo patterns you see when you look at small, bright lights through a tiny pinhole in a piece of aluminum foil or through a transparent curtain. The wave theory also explained why the steam very close to the stack of a locomotive or teakettle spout is invisible. But most convincing of all, the wave theory led a physics teacher, who was trying to illustrate the wave theory to his class, to build an electric device that would make big demonstration-size light waves. The device Professor Hertz made for the class of 1887 turned out to be the first radio wave transmitter.

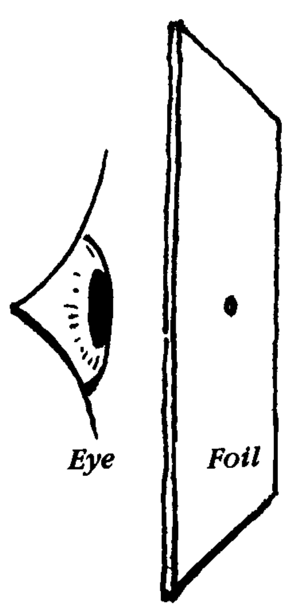

Figure 1-7. Make a very tiny pinhole in some aluminum foil. Then go for a night walk and look at very distant streetlights through the hole.

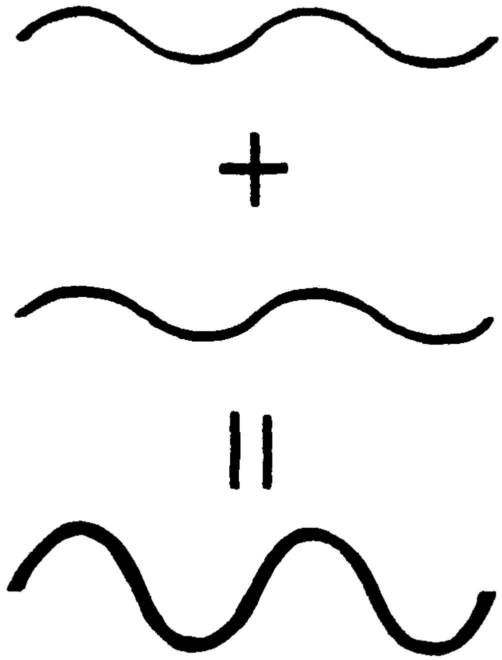

Figure 1–8. These waves are combining so as to reinforce each other. That is, they are added together in phase.

Figure 1–9. These waves are combined so as to cancel each other. That is, they are added together out of phase. The waves are exactly one-half cycle (180 degrees) out of phase, which causes complete destructive interference. But this seems like a violation of conservation of energy. If light cancels light, where does the energy go? It turns out that every time light cancels light at one location there is another location—usually very nearby—where light reinforces light, and all the energy that is missing from the canceled location shows up at the reinforced location. This is true for sound, water, or any other kind of wave.