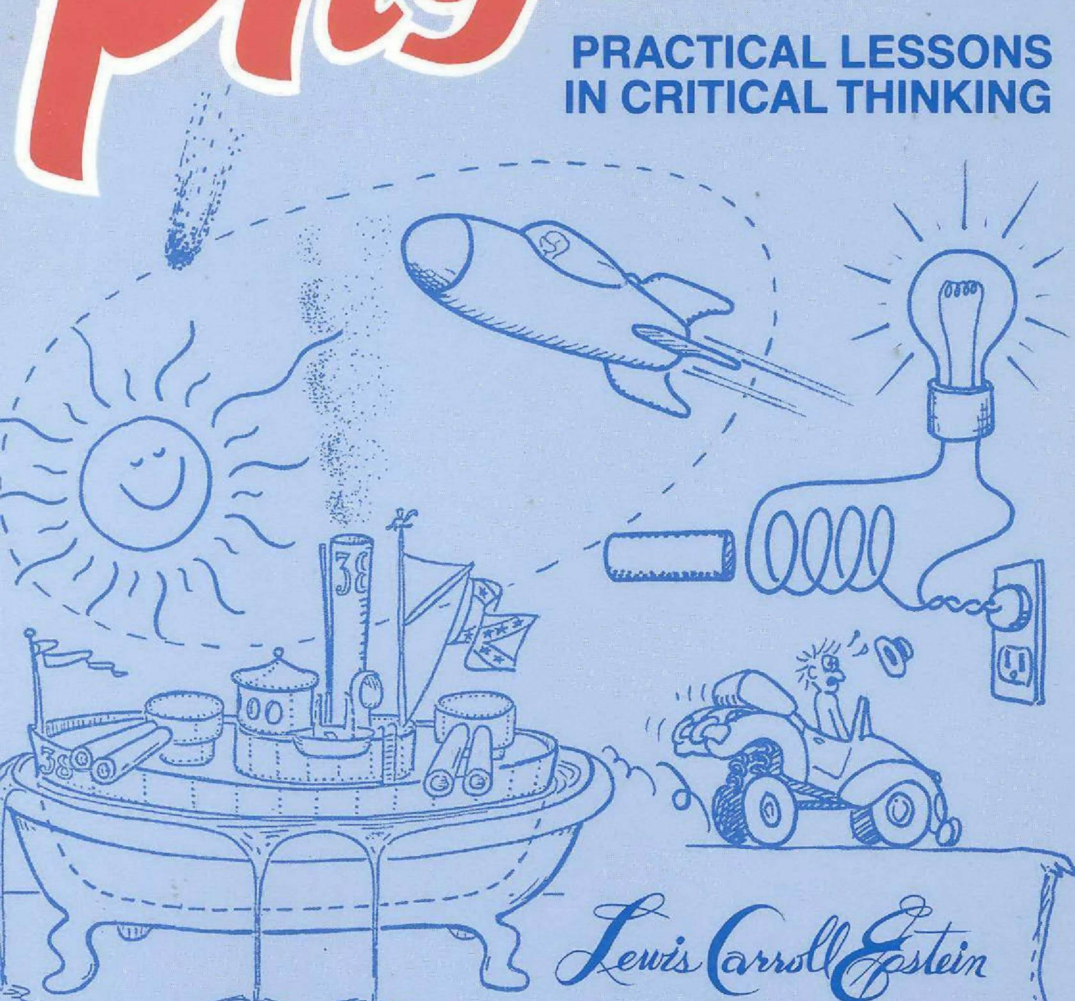
$27.95

THINKING *Physics*

PRACTICAL LESSONS IN CRITICAL THINKING



Lewis Carroll Epstein

THINKING Physics IS GEDANKEN PHYSICS

SECOND EDITION

THINKING Physics IS GEDANKEN PHYSICS

SECOND EDITION

Lewis Carroll Epstein

City College of San Francisco

INSIGHT PRESS

614 Vermont St., San Francisco, CA 94107

ACKNOWLEDGEMENTS

To Debra Lynn Bridges who did most of the editing for this book.
To Bill Rock, who did most of the typesetting for this book and contributed many editorial and pedagogical improvements.
To the many friends, students and colleagues whose discussions, criticisms and encouragement have been an essential part of putting this book together.

Insight Press
614 Vermont Street
San Francisco, CA 94107

DEDICATION

Most people study physics to satisfy some requirement. Some study physics to learn the tricks of Nature so they may find out how to make things bigger or smaller or faster or stronger or more sensitive. But a few, a very few, study physics because they wonder — not how things work, but why they work. They wonder what is at the bottom of things — the very bottom, if there is a bottom.

This book is dedicated to those who wonder.

HOW TO USE

The best way to use this book is NOT to simply read it or study it, but to read a question and STOP. Even close the book. Even put it away and THINK about the question. Only after you have formed a reasoned opinion should you read the solution. Why torture yourself thinking? Why jog? Why do push-ups?

If you are given a hammer with which to drive nails at the age of three you may think to yourself, "OK, nice." But if you are given a hard rock with which to drive nails at the age of three, and at the age of four you are given a hammer, you think to yourself, "What a marvelous invention!" You see, you can't really appreciate the solution until you first appreciate the problem.

What are the problems of physics? How to calculate things? Yes—but much more. The most important problem in physics is *perception,* how to conjure mental images, how to separate the non-essentials from the essentials and get to the heart of a problem, HOW TO ASK YOURSELF QUESTIONS. Very often these questions have little to do with calculations and have simple yes or no answers: Does a heavy object dropped at the same time and from the same height as a light object strike the earth first? Does the observed speed of a moving object depend on the observer's speed? Does a particle exist or not? Does a fringe pattern exist or not? These qualitative questions are the most vital questions in physics.

THIS BOOK

You must guard against letting the quantitative superstructure of physics obscure its qualitative foundation. It has been said by more than one wise old physicist that you really understand a problem when you can intuitively guess the answer *before* you do the calculation. How can you do that? By developing your physical intuition. How can you do THAT? The same way you develop your physical body—by exercising it.

Let this book, then, be your guide to mental push-ups. Think carefully about the questions and their answers *before* you read the answers offered by the author. **You will find many answers don't turn out as you first expect. Does this mean you have no sense for physics? Not at all. Most questions were deliberately chosen to illustrate those aspects of physics which seem contrary to casual surmise. Revising ideas, even in the privacy of your own mind, is not painless work.** But in doing so you will revisit some of the problems that haunted the minds of Archimedes, Galileo, Newton, Maxwell, and Einstein.* The physics you cover here in hours took them centuries to master. Your hours of thinking will be a rewarding experience. Enjoy!

Lewis Epstein

*__Gedanken__ Physics was Einstein's expression for Thinking Physics.

CONTENTS

In learning the sciences examples are of more use than precepts.
—Sir Isaac Newton

Mechanics

Mechanics began with the energy crisis—which began with the beginning of civilization. To make a machine that would put out more work than went into it is an ancient dream. Is it an unreasonable dream? After all, a lever puts out more force at one end than is applied to the other end. But does it put out more work? Does it put out more motion? If the lever fails, might some other scheme lead to the ultimate goal, perpetual motion? It may be said the (unsuccessful) quest to make gold launched chemistry and the (unsuccessful) quest of astrology launched astronomy. The (unsuccessful) quest for perpetual motion launched mechanics.

You may have noticed that the biggest section of this book (as well as many other physics books) is the MECHANICS section. Why is mechanics so important? Because it is the goal of physics to reduce every other subject in physics to mechanics. Why? Because we understand mechanics best. Once heat was thought to be some sort of a substance; later it was found to be just mechanics. Heat could be understood as little balls called molecules bouncing about in space or connected to each other by springs and vibrating back and forth. Sound has similarly been reduced to mechanics. Much effort has been spent trying to reduce light to mechanics.

Mechanics has two parts—the easier part, **statics,** where all forces balance out to zero so nothing much happens, and the dramatic part, **dynamics,** where all the forces do not cancel each other, leaving a net force that makes things happen. How much happens depends on how long the force acts. But "long" is ambiguous. Does it mean long distance or long duration? The simple but subtle distinction between a force acting so many feet and a force acting so many seconds is the magic key to understanding dynamics.

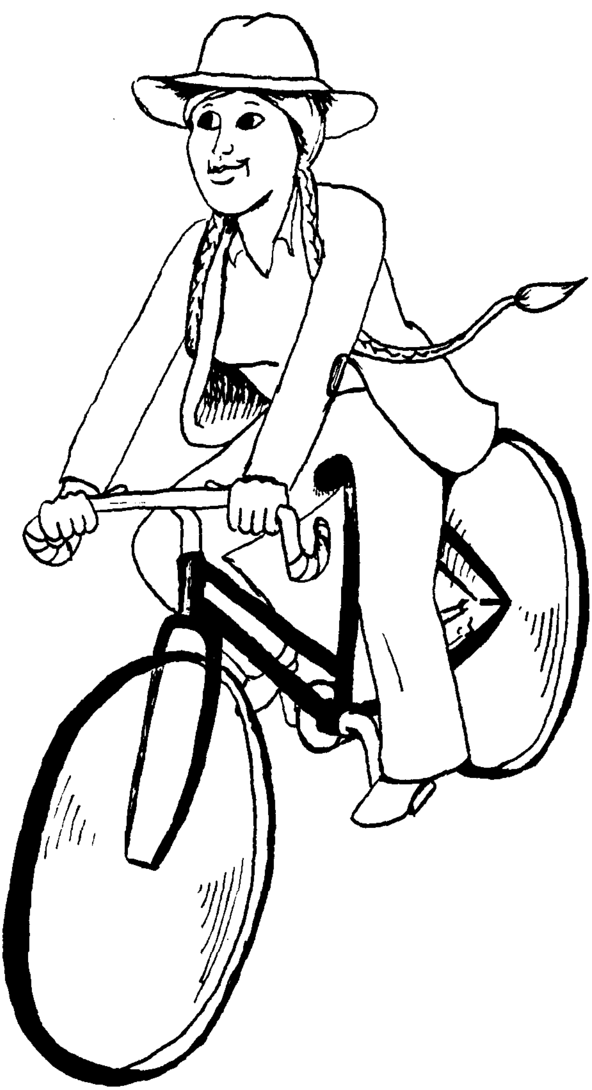
You'll also notice that a good deal of attention is devoted to situations involving collisions (Splat, Gush, Smush, and so on). Granted collisions are interesting in their own right, but are they all that important? Many physicists believe they are. Why? Because if all the world is to be explained mechanically in terms of little balls (molecules, electrons, photons, gravitons, etc.), then the only way one ball affects another ball is if the little balls hit. If that is so, collision becomes the essence of physical interaction.

Now it may be the goal of physics to reduce every subject to mechanics and to reduce mechanics to collisions, but certainly that goal has not been and might never be reached. Nonetheless, if you are to understand physics, you must first understand mechanics. Perhaps even love mechanics.

VISUALIZE IT

Suppose you are going for a long bicycle ride. You ride one hour at five miles per hour. Then three hours at four miles per hour and then two hours at seven miles per hour. How many miles did you ride?

a) five
b) twelve
c) fourteen
d) thirty-one
e) thirty-six

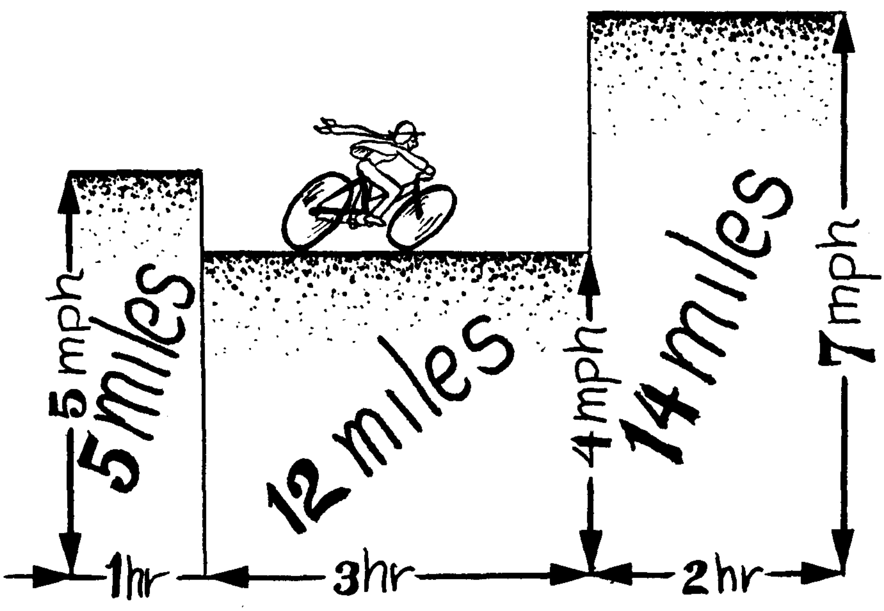


ANSWER: VISUALIZE IT

The answer is: d. Remember speed multiplied by time is distance. But what is the speed? It changes during the ride. So split the trip up into segments. One hour at five mph gives five miles. Three hours at four mph gives twelve miles and two hours at seven mph gives fourteen miles. Then add the segments. Five plus twelve plus fourteen sum to thirty-one. So that is the answer, that's it.

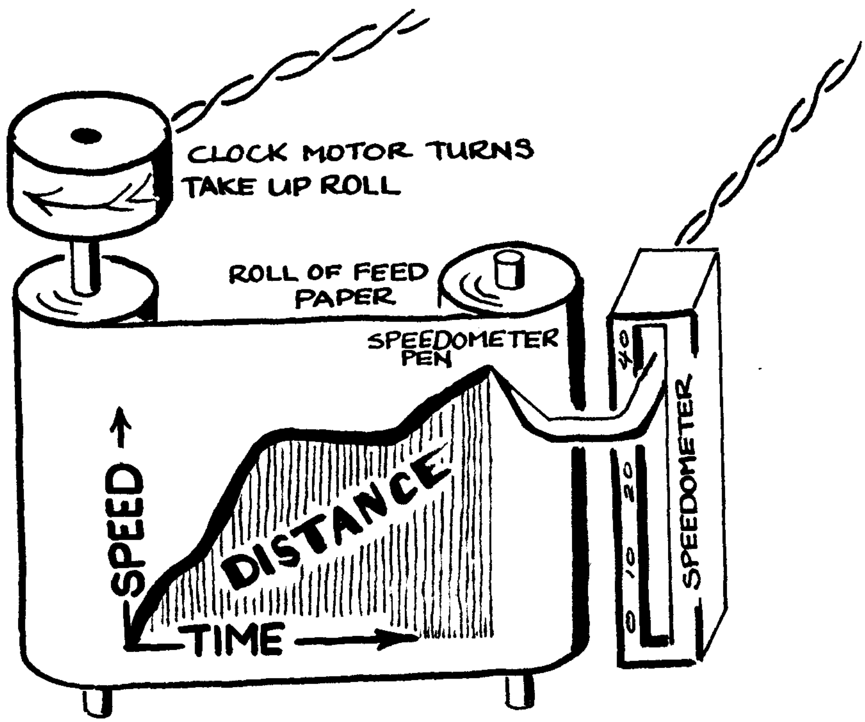
Yes, that is the answer, but that is not it. That is just some arithmetic. Arithmetic is blind. Can you visualize what you are doing? To visualize, use geometry. Geometry has eyes.

Make a graph showing the history of the ride. For one hour it is at five mph. Then it drops to four mph and stays there for three hours. Then it jumps up to seven mph for two hours and finally it drops to zero which means the bike stops.



Now split the graph into three rectangles. Each rectangle represents one segment of the trip. The first rectangle is 5 mph high and 1 hour wide. What is the area of this rectangle? Multiply its height by its width—that is, multiply 5 mph by 1 hour—and you get 5 miles. The area of the rectangle is the distance covered during the first segment of the ride. Likewise the area of the second rectangle is 4 mph multiplied by 3 hours which is 12 miles. So the area of each rectangle is equal to the distance traveled on that segment of the ride.

That gives you a nice way to visualize distance traveled. Imagine a recording speedometer that gives you a graph of your speed plotted against time. The total area under the speed curve must tell how far you have traveled.



RECORDING SPEEDOMETER

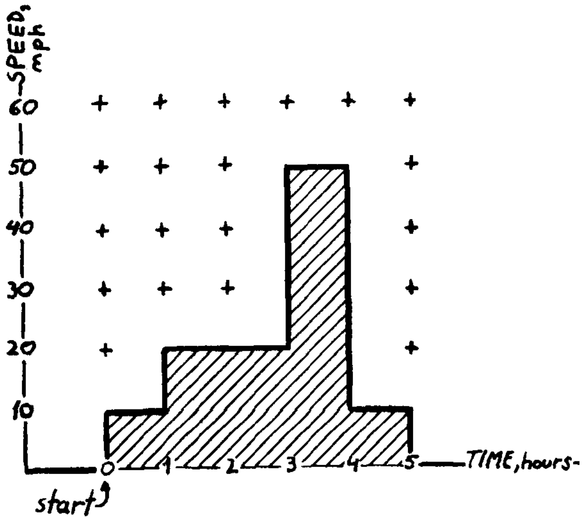
INTEGRAL CALCULUS

Look at the speed graph and then answer these questions. Two hours into the trip how fast was the thing going?

a) zero mph
b) 10 mph
c) 20 mph
d) 30 mph
e) 40 mph.

How far did the thing go during the whole trip?

a) 40 miles
b) 80 miles
c) 110 miles
d) 120 miles
e) 210 miles.



ANSWER: CALCULUS

The answer to the first question is c. Above the 2-hour mark the speed graph reads 20 mph.

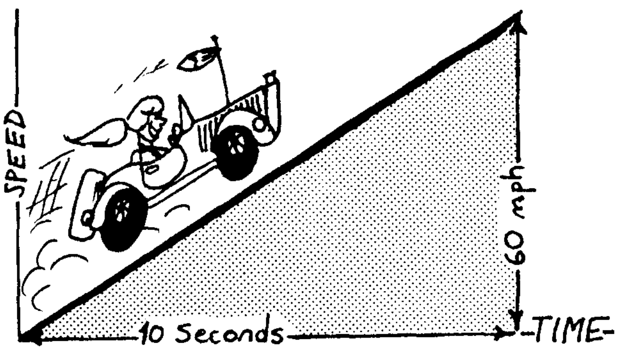
The answer to the second question is also c. The area under the speed line (or curve) is divided into little squares. Each square is 1 hour wide and 10 mph high. That means the area of each little square is 10 miles. Now count the little squares under the curve. There are eleven in all. Eleven times ten miles equals 110 miles. So the total area under the graph is 110 miles and that's how far the thing went during the whole trip. How can the area of a square represent miles? Must it not represent square miles? The area of a square represents square miles if its width and height are measured in miles, but if its width is measured in hours and its height in miles per hour, and you have imagination, its area is miles.

The technique you used here for finding the distance traveled is the technique of Integral Calculus. Integral means to integrate or sum many small parts. Calculus refers to many very small parts or layers which build up to make the sum. The name comes from minerals which build up in layers such as the calculus which builds up on your teeth. As the dentist scrapes it it flakes off. Each flake is a layer.

DRAGSTER

A dragster starts from rest and accelerates to 60 mph in 10 seconds. How far does it travel during those 10 seconds?

a) 1/60 mile
b) 1/12 mile
c) 1/10 mile
d) 1/2 mile
e) 60 miles.



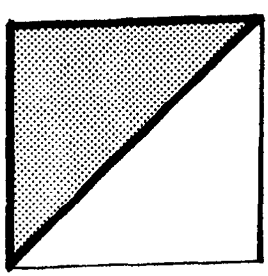
ANSWER: DRAGSTER

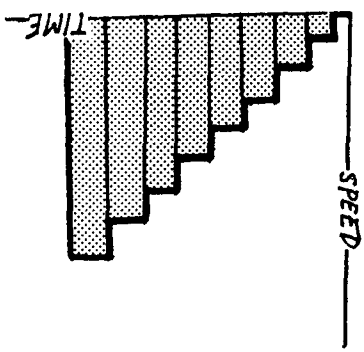
The answer is: b. First let's get everything in hours. Ten seconds is 1/6 of a minute and 1 minute is 1/60 of an hour, so 10 seconds is 1/360 of an hour.

The area under the speed line is a triangle and the area of a triangle is one-half of its height multiplied by its length. The triangle area is one-half the height multiplied by the length because the area of the triangle is half the area of the rectangle and the area of the rectangle is height mutiplied by length.

The height of the triangle is 60 mph and its length is 1/360 part of an hour so total distance moved must be (½) × (60 mph) × (1 hr/360) = 1/12 of a mile.

You can, if you want, think of the triangle as made up from a bunch of constant-speed steps. Each step is one layer of calculus.

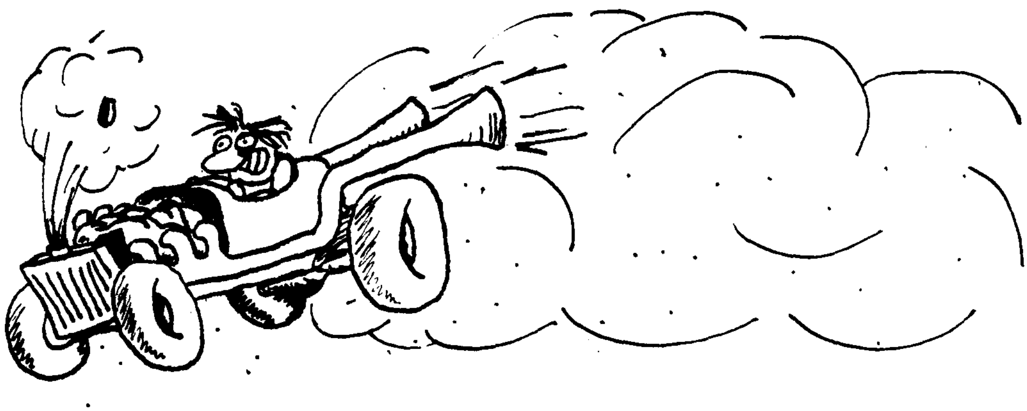




NO SPEEDOMETER

The next dragster is so stripped down that it does not even have a speedometer. At maximum acceleration from rest it goes 1/10 of a mile in 10 seconds. What speed did it get up to in those ten seconds?

a) 6 mph, b) 52 mph, c) 60 mph,
d) 62 mph, e) 72 mph.



ANSWER: NO SPEEDOMETER

The answer is: e. This is almost a rerun of DRAGSTER. The rule was: $(\frac{1}{2}) \times$ (maximum speed) $\times$ (time) = (distance).

So in this case $(\frac{1}{2}) \times (?\ \text{mph}) \times (1\ \text{hr}/360) = 1\ \text{mile}/10$.

Divide both sides of this equation by 1 hr/360. Remember 1 hr/360 divided by 1 hr/360 equals one, and 1 mile/10 divided by 1 hr/360 equals 36 mph, so: $(1/2)(?\ \text{mph}) = 36\ \text{mph}$.

Finally: $?\ \text{mph} = (2) \times (36\ \text{mph}) = 72$ miles per hour.