CONVERSATIONS ON THE DARK SECRETS OF PHYSICS

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and
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PREFACE

The idea for this book began over four decades ago when Edward Teller began teaching physics appreciation courses at the University of Chicago.

Then, as now, Dr. Teller believes that illiteracy in science is an increasingly great danger to American society, not only for our children but also for our growing adult population.

On one hand, the future of every individual on this globe is closely related to science and its applications. Fear of the results of science, which has become prevalent in much of the Western World, leads to mistaken decisions in important political affairs. But this book speaks of no fears and of no decisions—only of the facts that can prevent one of them and indirectly guide the others.

From the perspective of this book, a second point is even more significant. The first quarter of this century has seen the most wonderful and philosophically most important transformation in our thinking. The intellectual and aesthetic values of the points of view of Einstein and Bohr cannot be overestimated. Nor should they be hidden at the bottom of tons of mathematical rubble.

Our young people must be exposed to science both because it is useful and because it is fun. Both of these qualities should be taken at a truly high value.

Adults should be interested in science because it is a part of our cultural heritage and because the new technologies that are entering our society should be understood by as many of us as is possible.

It is our hope that this book will enable many otherwise-educated adults to catch up on the new physics so that they can properly contribute to the dialogue on the scientific and technological decisions that will shape our future. Also, we invite them to join us in an appreciation in the sheer joy of science.

The reader will find that equations are used in the text. Some writers avoid any and all equations, fearing that they will frighten off readers. We have deliberately included them to summarize the words in the text, and the lay reader need not be afraid to glance at them and even make a small attempt to decode them (the key to the code is always provided in the text). Like the sketches which also illustrate the words in this book, equations should be thought of as a form of summary.

To capture the essence of his lectures, Dr. Teller and his daughter, Wendy, began working on a manuscript. (As you will see, the footnotes in the text sometimes contain a dialogue between ET and WT.) They were joined in their effort by Wilson Talley (who also appears in the footnotes, joining the original WT).

The precipitating event that led to the completion of this book was an action by the Fannie and John Hertz Foundation. The Foundation, established by the founder of the Hertz Corporation and the Yellow Cab Company, began a series of experiments in undergraduate education, including students at primary and secondary schools. Among other projects, it was decided that Dr. Teller would be supported in teaching an updated "Physical Sciences Appreciation" course to high school students and teachers in the Livermore Valley area of California. The course was sponsored by the Foundation, the University of California, Davis/Livermore Department of Applied Science, and the Lawrence Livermore National Laboratory. We are indebted to those literally hundreds of students, as well as the thousands who have heard Dr. Teller speak on the appreciation of science over the past decades.

Along the way to completing this book, we owe a particular debt to several individuals. Paul Teller, Edward's son, read portions of the manuscript. Joanne Smith, Patty French, and Judy Shoolery took dictation, typed, and retyped various parts. Helen Talley, Wilson's wife, entered much of the original manuscript into the Macintosh and then gamely read subsequent versions for intelligibility. Because the "proof of concept" of the book was the course given at Livermore, we should credit Sue Anderson, Matt DiMercurio, Tom Harper, Barbara Nichols, Jaci Nissen, Maria Parish, Kathryn Smith, and Charlie Westbrook for their assistance in keeping that activity on line.

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PROLOGUE—A WARNING

"... *Denn die Bücher ohne Formeln*
Haben meistens keinen Sinn ..."
—From an apocryphal adaptation*
of the *Three Penny Opera*

I will use mathematics because physics without mathematics is meaningless. Some readers don't know mathematics so I will try not to use mathematics without explaining it, and those readers who already know it will have to be patient and might even enjoy it, since I will try to explain in an unusual way. I want to warn you—I will say quite a few things that everybody understands and I will say a few things that nobody understands and even some things that nobody can understand. I take this liberty because it is an actual picture of what scientists do. If somebody follows everything I say (it may

* This adaption was written about 1932 by an obscure Hungarian poet for Max Born's fiftieth birthday.

happen) I will be very pleased. But I do not expect it, because the world is usually so put together that everyone runs into something he doesn't understand and experiences the limit of what he can understand. I would like to demonstrate that these limits exist.

I have one more philosophical (i.e., irrelevant) remark. It is often claimed that knowledge multiplies so rapidly that nobody can follow it. I believe that this is incorrect. At least in science it is not true. The main purpose of science is simplicity and as we understand more things, everything is becoming simpler. This, of course, goes contrary to what everybody accepts.

I will start by explaining Einstein which is considered the most complicated of tasks. Nobody can understand Einstein. An American soap advertisement claims its product is 99.44% pure. This, in America, is a very good standard. I claim that 99.44% of the western intellectuals have no idea what Einstein's theory is, what it means. I want you to join the remaining 0.56%.

I claim that relativity and the rest of modern physics is not complicated. It can be explained very simply. It is only unusual or, put another way, it is contrary to common sense.

The human mind is made in such a way that if I say something that you think is absurd the automatic reaction is that your earflaps come down and you stop listening. You should make an effort and continue to listen, remembering that I am going to say things that are "obviously" wrong; in fact, they are true.

Chapter 1

RELATIVITY

Space and Time of the Physicist

In which a simple, absurd but correct proposal of Einstein's is described which establishes the framework for physics.

I begin with the theorem of Pythagoras. As you probably know, Pythagoras was a Greek who lived in southern Italy. He was a philosopher, which, at that time, meant he was also a mathematician. He was a physicist. Unfortunately, he became involved in politics and therefore got into trouble. (In that, as in many other regards, some followed in his footsteps.)

The theorem of Pythagoras was known to the Babylonians a thousand years before Pythagoras, but to our knowledge Pythagoras was the first to prove it. The proof I will give is different from the one that Pythagoras found. It is also not precise, but it can be made precise if anybody is really interested in precision.

In Figure 1, we have a triangle with sides of length a, b, and c. The sides a and b form a right angle. Squares have been drawn on

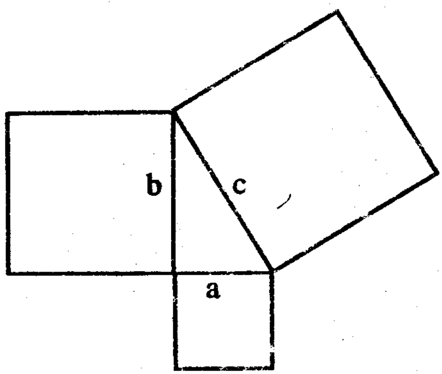

Figure 1. The Pythagorean theorem says that the sum of the squares of the legs of a right triangle is equal to the square of the hypotenuse.

each of the sides. The area of the square constructed on the side of length a is a^2 (a^2 means a times a). Similarly, the area of the square constructed on the side of length b is b^2 and the area of the square constructed on the side of length c is c^2. The theorem of Pythagoras says that $a^2 + b^2 = c^2$, that is, the sum of the areas of the two smaller squares is equal to the area of the big square.

To prove the theorem I draw two equal squares as in Figure 2. From each I will subtract four triangles, all equal in size but arranged differently. The four triangles are equal in area and the two big squares are equal in area, so the shaded area in the first square must be equal to the shaded area in the second square. Now the little square in Figure 2a has an area of a^2 and the larger square has an area of b^2. The shaded area in Figure 2b has an area of c^2. Thus we see that $a^2 + b^2 = c^2$.

The next statement, which we shall not prove, is, in a way, much more difficult, in a way much simpler. What is simple, what is difficult is different for different people.

As an introduction I want to draw in Figure 3 what is known as a Cartesian Coordinate system, named after the French philosopher Descartes. We have two perpendicular lines on a plane. Suppose

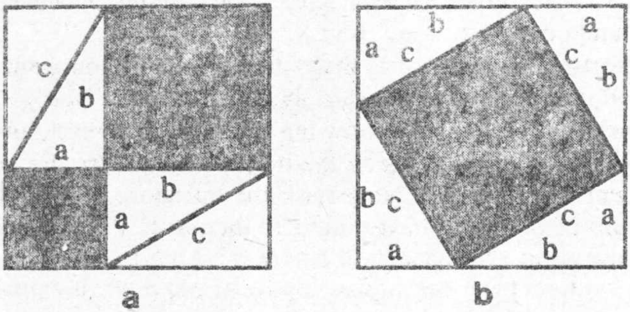

Figure 2. Copies of the triangle of Figure 1 can be rotated and flipped without changing the area. We can then rearrange these copies as in the two large squares to demonstrate that (a) the square of side *a* plus the square of side *b* will equal (b) the square of side *c*.

we have a point labeled *P*. If one starts at the intersection of the two lines, called the origin, one can reach *P* by moving a certain distance *x* along the horizontal line and then moving a certain distance *y*, parallel to the vertical axis. Then the two numbers *x* and *y* determine

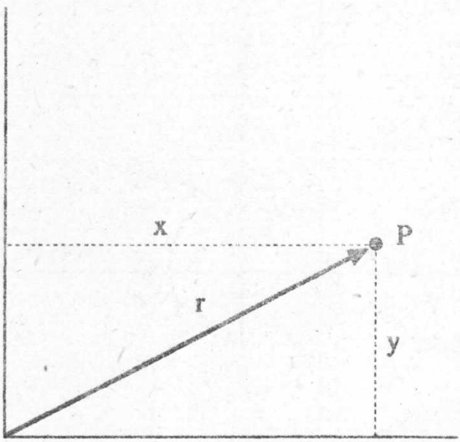

Figure 3. In the Cartesian coordinate system, the point *P* is reached by moving *x* units along the horizontal axis and *y* units up the vertical axis.

the point P. According to Pythagoras, the distance r between the point P and origin is $r^2 = x^2 + y^2$.

Unfortunately, space has three dimensions. If you want to fix a position in space and if you start at some "origin," then you have to say how far you go north, how far you have to go east, and how far you have to go up to reach the point. These three dimensions will be called x, y, and z. Now I ask the question: how far have I gone from the origin if I have gone x to the north, y to the east, and z up to the point P? The answer is $r^2 = x^2 + y^2 + z^2$.

To see how I get this answer, I look at point P', directly below P in Figure 4. By using Pythagoras, I know that the distance r' between P' and the origin is obtained from $(r')^2 = x^2 + y^2$. Now I consider the three points P, P', and the origin. If I connect these points with lines, they form a right-angled triangle and I can apply Pythagoras again, obtaining the answer

$$r^2 = (r')^2 + z^2 = x^2 + y^2 + z^2.$$

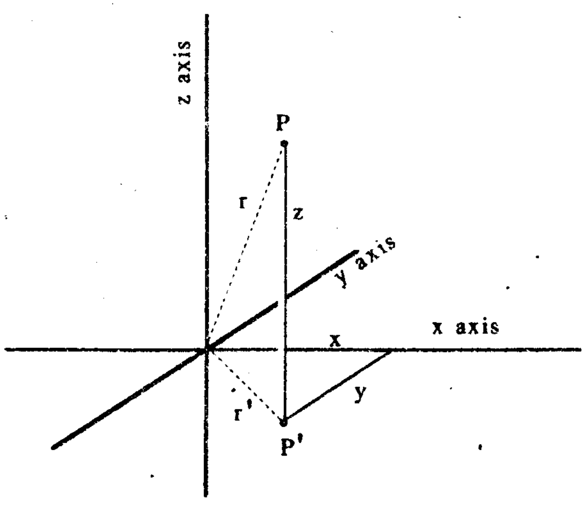

Figure 4. The Pythagorean theorem allows us to find r, the distance from the origin to the point P, in three dimensions as well as two.

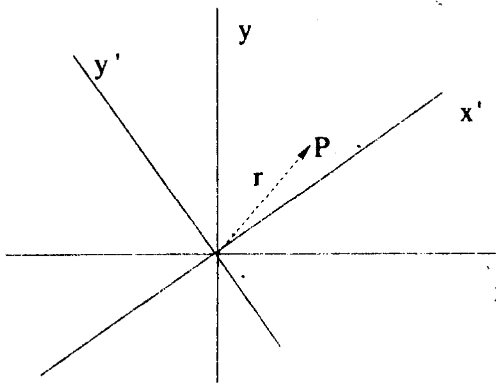

Figure 5. Rotation of the axes x and y into x′ and y′, does not alter the distance from the origin to the point *P*; *r* is an invariant in this case.

So far I have dealt only with equations. Now I want to introduce an idea and this idea is an "invariant." An invariant is a quantity that does not change if you do certain things. For example, the distance between two points is an invariant under certain conditions. Consider the distance *r* in Figure 5. I could change the coordinate system. I will rotate the x and y lines (or axes, as they are called) and get the new x′ and y′ axes which are perpendicular to each other. Then I can get to the point *P* by going a distance x' along the x′ axis and then going a distance y' parallel to the y′ axis.* Then you can see that in the new coordinate system the numbers x' and y' which characterize *P* are different from x and y, but r remains the same. Therefore, I can say that I have an invariant $(x')^2 + (y')^2 = x^2 + y^2 = r^2$. No matter how I rotate my coordinate system, I get the same value of r, even though my values for x and y have changed.

* Please do not be confused that I call the axis and the distance one travels along the axis by the same name. This is what mathematicians do; they claim they are precise and then become completely imprecise. Physicists are worse, they claim they aren't precise and then, precisely when you aren't looking, they become precise.

Having discussed a little mathematics, we can start to talk about relativity. I now will discuss events, instead of points. In order to specify an event, I need four numbers: x, y, and z to specify the position and t to specify the time of the event. Four numbers are needed to describe each point and therefore we are discussing four dimensions. You may think that I am cheating, because time is very different from space. You will soon see that time is not all that different from space and this is the main point of Einstein's special relativity.

Let us start from the view that time and space are quite different. Suppose I am driving a car at 60 mph on a straight road. I push in my cigarette lighter and at the same instant I pass a hitchhiker. The cigarette lighter takes 15 seconds to pop out. I have two events; the first is my pressing the cigarette lighter in and the second is the cigarette lighter popping out. The hitchhiker will tell you (with few kind words for me) that the two events occurred 1/4 mile apart (since in 15 seconds, 1/4 of a minute, I have traveled 1/4 mile). I, on the other hand, will tell you that both events happened in the same place, about one foot from me, forward, and a little to the right. As far as I am concerned, I can say that the car is at rest and the world is moving backward.

The hitchhiker and I disagree on the distance between the two events. In this four dimensional world, in this geometry of space and time, r is no longer an invariant!

The circumstance that r is not an invariant was discussed very thoroughly several hundred years ago. This discussion is a part of what is called Galileo's principle, which says that the laws of physics are the same whether you describe the events as seen by an observer at rest or an observer in motion. But while the distance r is no longer an invariant, the time t, 15 seconds, that has passed between the two events is an invariant. The time is 15 seconds according to the watch that the hitchhiker is using and according to the watch that I am using. On that we all agree. It was true from the beginning, whenever that happened, up to the year 1905.

In the year 1905, the view that time is an invariant was changed by Einstein. This is the absurdity that I will discuss, namely, the time measured by me and the time measured by the hitchhiker are not the same. Einstein claims that the times don't agree, but he also says that there exists, instead, a different invariant.

Take two events. Suppose that t is the time between the two events, as measured by some observer, whether it is by me or the hitchhiker or some other observer who moves with respect to both me and the hitchhiker. We will call the speed of light c, it is 3×10^{10} cm/sec. Then ct is the distance that light can travel in the time between the two events, for instance, in 15 seconds. That is a big distance, a little more than a dozen times the distance to the moon. We shall, as before, call the observed distance between the two events r. Then we take the distance ct, square it, and subtract from it the square of the distance between the two events. We have then $(ct)^2 - (r)^2$.

In Einstein's theory, r is not an invariant, t is not an invariant, but $(ct)^2 - (r)^2$ is an invariant. This means that $(ct)^2 - (r)^2$ always has the same value, no matter whether I use my values for t and r or the hitchhiker's values for t and r or some other observer's values for t and r.

In the case we have been discussing from my viewpoint, $(ct)^2$ is very large (about twelve times the distance to the moon, squared) and r^2 is zero. From the hitchhiker's point of view, r^2 is $(1/4 \text{ mile})^2$, which is very small compared to my value for $(ct)^2$. Thus the difference between the time he observes and the time I observe is very small, so small that no one can measure it. So why all the fuss?

Let me jump to a case where Einstein's theory makes all the difference in the world. Let us say, for simplicity, that the moon is one light second away. (Actually, its distance is a little more than one light second.) That means that light takes just one second to go from the earth to the moon. Now I will send a light beam to the moon. I have two events: the first is the light beam leaving the earth, the second is the light beam arriving on the moon. I take the first event to be my initial point; the second event is 1 second later and 3×10^{10} cm away. That is, $c = 3 \times 10^{10}$ cm/sec, $t = 1$ sec, and $r = 3 \times 10^{10}$ cm, so $(ct)^2 = (3 \times 10^{10})^2$, $r^2 = (3 \times 10^{10})^2$, and $(ct)^2 - r^2 = (3 \times 10^{10})^2 - (3 \times 10^{10})^2 = 0$.