AN EVENING WITH ALBERT EINSTEIN AND ISAAC NEWTON

February 2007.

<u>**Personae Dramatis**</u>:
Albert Einstein
Sir Isaac Newton
Dr. Cohen (Philosopher and Historian of science)
Commentator:

Location: 112 Mercer Street, Princeton.
Time: March 16, 1955

The play takes place in Albert Einstein's house, 112 Mercer Street, in Princeton, in March of 1955, just a few days after his 76th birthday. The commentator introduces the play.

Prologue:
Good evening ladies and gentlemen. Welcome to this very special occasion to celebrate the 102nd anniversary of the three great papers that the young Albert Einstein published in the *Annalen der Physik* in 1905. In his miracle year, now referred to as *annus mirabilis*, Einstein's three revolutionary papers; on Brownian motion, the quantum nature of radiation, and relativity theory, were not immediately accepted, or even acknowledged. However, the ideas developed in these papers were all trail-blazing, and set the program for the new physics in the 20th century. The conversation also briefly touches on the general theory of relativity. Tonight, we will use for our play, as our poetic license, the famous personal manifesto of Professor Einstein:

For those who believe in physics, the distinction between past, present, and future is only a stubbornly persistent illusion.

The play is based on an article that Dr. Cohen, a noted historian of science, wrote and published in *The Scientific American* in 1955. The article discusses his one hour conversation with Einstein in his house in Princeton, just two weeks before he died.

The play is presented in two scenes. In scene 1 you will meet Dr. Cohen, a young historian and philosopher of science from Harvard University, who is now specializing in the works of Newton. He was trained in physics and mathematics and later became a Professor at Harvard University. Professor Einstein has graciously consented to an interview with Dr. Cohen.
A little pause to anticipate the reaction of the audience.

To make things interesting, we have been able to contact Sir Isaac Newton. He was able to travel into the future. But we will explain the physics of this later.
He will join us a little later, once the tone of the interview is set. Dr. Cohen will act in the capacity of a moderator. I hope that our young scholar will not be totally overwhelmed in the presence of these two giants of science.
He stops for a few seconds and then continues.

SCENE 1:

We see Einstein’s study: chairs, a table, books, an assortment of pipes.
On the table we see:

A large wooden sphere, attached to a long string and hanging from a stand.
(This is one of Einstein’s “toys” that he calls the ‘ubiquitous pendulum’).
A long, thin cylindrical object that looks like a toy (Einstein’s birthday present).
A large toy radiometer.
An incandescent lamp (show-case lamp, with the long filament visible).
A solenoid and magnet, connected to a galvanometer.
A large spinning top, or gyroscope, often used as a toy.
A large globe of the earth (this dominates the scene).
(We also see a violin on the table).

Dr. Cohen arrives, carrying a paper pad and pen, sits down, scribbles something and then addresses the audience.

Dr. Cohen:
I just met Frau Dukas, Professor Einstein’s secretary and she asked me to make myself comfortable. Professor Einstein will arrive presently.
He stops for a few seconds and then continues.

To make things even more interesting, we have been able to contact Sir Isaac Newton. He was able to travel into the future. But we will explain the physics of this later.
I have asked Isaac Newton to join us a little later. Professor Einstein is aware that I would like to talk to him about my researches concerning the work of Newton and how this work relates to his. But he does not know that Sir Isaac will be here in person.
Frau Dukas, however, assured me that the Professor likes surprises.
He looks at Einstein’s desk, picks up a few of the items and places them back again.
Finally, he picks up one the pipes and smiles.
Suddenly Einstein arrives. He wears an open shirt, a blue sweat shirt, grey flannel trousers, and leather slippers. He smiles warmly.

Einstein:
Welcome, Dr. Cohen. I have been looking forward to meeting you. I trust you had a pleasant journey. How was your trip?

Dr. Cohen:
Very pleasant, - except that it is still surprising to find myself in Einstein’s house at 112 Mercer Street, actually talking to him.

Einstein:
Yes, I can imagine.

Dr. Cohen:
Professor, Einstein, I remember reading somewhere that you once said: “This house will never become a pilgrimage, where the pilgrims come to look at the bones of the saint”.

Einstein:
Yes. I do hope that will be the case.
He smiles and then points to the desk and then walks there.

Two days ago was my 76th birthday. ...You can still see a balloon that one of the neighbour’s children brought over. You know, I enjoy being with children and talking to them to find out how they think about the world around them.

Dr. Cohen:
But ... how do you answer a child when they ask about the theory of relativity?
I am sure that your neighbours tell them that that is why you are famous.

Einstein:
Well, I have recently thought of a nice way to explain relativity to them.
I simply say, at least to the older ones: “Put your hand on a hot stove for a minute, and it seems like an hour. Sit with a pretty girl (or handsome boy) for an hour, and it seems like a minute. THAT’S relativity.
Both laugh heartily.

Dr. Cohen:
That is very funny—and probably instructive.

Einstein:
You know, I sometimes ask myself how it came about that I was the one to develop the theory of relativity. The reason, I think, is that a normal adult never stops to think about problems of space and time. These are things which one has thought about as a child. But my intellectual development was slow, as a result of which I began to wonder about space and time only when I had already grown up.”

Dr. Cohen:
Yes. I have always thought we should introduce your ideas in the school curriculum earlier.

Einstein:
But, don’t forget, there was a time when relativity was not accepted by many. I was actually quoted to say that: “If relativity is proved right, the Germans will call me a German, the Swiss will call me a Swiss citizen, and the French will call me a great scientist. If, however, relativity is proved wrong, the French will call me a Swiss, the Swiss will call me a German, and the Germans will call me a Jew”.

Dr. Cohen:
I am glad that you are now regarded as a great scientist everywhere.

Einstein:
Thank you. But there are still doubters, you know.
Einstein nods and then continues, pointing to the items on the table.

For the older (adult) guests I have my “toys” that I use to illustrate principles and ideas about my work.
Einstein points to a long cylindrical object.

This curious looking toy I received as a present from my neighbor, the physicist Eric Roger, who made it himself. He is a very clever physicist and I hear a dynamic teacher.
I will show you later that this toy demonstrates the basic idea that underlies my general relativity theory.
He points to the pendulum and the other items on the table.

The other items, except for the balloon, of course, are always here.
The “ubiquitous pendulum” is here to remind me of the modest beginnings of physics. I am also fond of the recently available toy, called a radiometer.
He picks these up and shows them to Dr. Cohen.

Dr. Cohen:
If I remember correctly, you contributed an article as late as 1921 to the physics of this wonderful toy.

Einstein:
Yes, indeed. The physics here is not easy. I wanted to put an end to the argument that it was radiation pressure that caused the motion of the vanes.
He continues....

I like to use this incandescent lamp to show interference patterns, especially the wave nature of light.
He picks up the Newton’s rings apparatus.

This is the simple lens and glass combination for the famous demonstration of Newton’s rings. Newton had great difficulty explaining these round interference patterns, using his corpuscular theory of light.
He picks up the Faraday demonstration apparatus.

And here is a solenoid and a bar magnet, the solenoid is connected to a galvanometer, to show the Faraday effect. This apparatus is very important to me, because, as you know, I used this simple example in the very first paragraph of my 1905 paper on relativity to argue for the theory of special relativity.

And here is a spinning top that demonstrates the phenomenon of precession. This phenomenon is connected to the general theory of relativity.
Finally, there is a large globe, not used as a geographical reference, but rather to illustrate the principles of non-Euclidean geometry to my visitors.

Dr. Cohen:
And the balloon?
Einstein smiles...
I am sure we will find a use for it later...

Einstein points to his violin.
Unfortunately, I find it difficult to play the violin anymore. I did enjoy so much to play with others.

He points to his pipes.
You seem to be amused at my many pipes. You know, I am not allowed to smoke anymore. But I still have to have a pipe in my hand when I think and write.

He smiles.
Do you smoke, Dr. Cohen?

Dr. Cohen:
No, I don't. Actually, I can't even think of one colleague who smokes.

Einstein:
That is good.
Excuse me, I cannot really think without a pipe in my hand.
He goes and carefully selects a pipe, then sits down in a comfortable chair. He crosses his legs and it is clear that he does not wear socks. He looks at Dr. Cohen and smiles.

You may have heard that I do not wear socks. I stopped wearing them a long time ago, when I discovered that within days there are always holes where the big toes are.
I am sure you have seen a picture of me and Frau Dukas sitting in the front row while a group was accepting their American citizenship in 1940. You can see me, attired appropriately in a suit and tie, crossing my legs, is obviously not wearing socks.
Einstein laughs heartily

Dr. Cohen:
Yes, it is one of the well known pictures of you, Professor Einstein.

Einstein:
He turns to Dr. Cohen
Well, … enough of this personal...
Young man, I realize that it is difficult for you to start a serious conversation with this old relic and saint.
There is a pause.

I would like to discuss my great predecessor, Isaac Newton. Although I have written forewords to a number of publications by and about Newton, I must admit I have not really studied the life of this great scientist
They both smile. Einstein continues:

Let me break the ice. I am surprised and pleased that a young man is interested in the history of science. I have found that the most difficult task in studying past science is to forget what happened afterwards. I have had discussions about history and philosophy of science before, with Bertrand Russell, Kurt Goedel, and Wolfgang Pauli, in this very room.

Dr. Cohen:
Do you remember any details about these discussions, Professor Einstein?

Einstein:
Yes, I do. But the most important conclusion we reached was that science without philosophy would be muddled and philosophy without history unthinkable.

Dr. Cohen:
Of course, I wholeheartedly agree with you. Which physicists (philosophers) had an influence on your thinking and your work?

Einstein:
Let's see. First of all, Newton. We will say more about this great scientist later. Next, Maxwell, who divined those four wonderful equations that united all of electricity and magnetism**,** showing that light was an electromagnetic phenomenon. Ernst Mach influenced my thinking in creating the general theory of relativity (relativity of motion and his idea of the source of inertia). Max Planck and his solution to black body radiation and last, but not least, the great Lorentz. Although I was not acquainted with his transformations when I wrote my paper in 1905, without his work, I would never have been able to make the discovery of special relativity.

Dr. Cohen:
I understand Max Planck was the first to respond to your papers of 1905.

Einstein:
Yes. I was very disappointed that those papers did not produce my expected response, at least not for a few years.

Dr. Cohen:
It must have been re-assuring for you to be recognized by Germany's greatest physicist.

Einstein:
Indeed. I am eternally grateful to him for this early recognition.
He stops for a while and then smiles. *He then says with emphasis*:

But you know Mach was a poor philosopher and Planck was not a good physicist.
Dr. Cohen looks up with astonishment

I thought that would get your attention.

Dr. Cohen:
It certainly did. But you cannot be serious, Professor Einstein!

Einstein:
Well, this is a little joke, Dr. Cohen, between you and me only. What I meant was that Mach was a poor philosopher since he never really recognized the existence of atoms, and - later even distanced himself from my special theory of relativity. That was a blow to me.
I thought Planck failed the test for being a good physicist when I found out that he was unable to sleep the night before Lord Eddington announced the result of the observation for the bending of starlight according to my general theory of relativity.
I did not loose any sleep at all. I knew the theory was right!
They both laugh.

Dr. Cohen:
Were you really that sure, Professor Einstein? Remember, had the first expedition been carried out in 1914, had it not been interrupted by the war, your value for the deflection of the light from a star in the gravitational field of the sun would have been ½ of the value which you correctly calculated only later. A value, by the way, one can also obtain from Newton's dynamics.

Einstein:
You are right. That was certainly a fortuitous event.
At that time I probably would not have been able to sleep!
He laughs and then becomes serious:

So you are a historian of science. I have written several articles about Newton, and have also read biographical sketches. History is clearly less objective than science. As I see it, there is an inner and intuitive and an external or documentary history. The latter is more objective, but the former is more interesting.

Dr. Cohen:
But the use of intuition can be dangerous; although, I admit, it is sometimes necessary when one wants to reconstruct the thought processes of someone who is no longer alive.

Einstein:
Or alive and old.
Einstein smiles and continues.

Recently someone asked me if the Michelson-Morley experiment had an influence on my 1905 paper. My God, that was 50 years ago! I answered in the affirmative, but, you know, now I am not so sure.
He reflects for a few seconds and then continues:

For example, I would like to know why Newton developed the concept of the ether, especially after his public statement of *hypotheco non fingo,* and the overwhelming success of his theory to make correct predictions, celestially and terrestrially.

Dr. Cohen:
He was obviously not satisfied with the idea that force could transmit itself through empty space, instantaneously.

Einstein:
Yes. But how can you document such an intuition? When I am asked how I came to think of this or that, I tend to respond by saying that I am a poor source of information concerning the genesis of my own ideas.

Dr. Cohen:
That is very interesting. Are you saying that, as a historian, I may have a better insight into the thought processes of Albert Einstein, than Albert Einstein himself?

Einstein:
In a way, yes.
But let us go back to the original question you had in mind when you entered my study. I am sure I can anticipate your question.
He looks at Dr. Cohen, with a twinkle in his eye

Yes, there are many unsolved problems in physics. There is so much we do not know: our theories are far from adequate.

Dr. Cohen:
Thank you, Professor Einstein. That is very close to what I was going to ask you first. I was going to start our conversation by saying that it is interesting that in the history of science great questions seem to be resolved, only to see them reappear in a new form. I would like to remind you that this is the 50th anniversary of the publication of your now famous papers of 1905, what is now known as the *annus mirabilis*.

Einstein:
My God is it that long ago? Still...it might be a good start, since this question is connected to the ideas expressed in those papers. These ideas seem to have had an impact on physics. How have they changed? This question is also connected to my work and how it relates to the work of the great Newton. But I also want to talk about Newton, the man.

Dr. Cohen:
That sounds very good, except that Frau Dukas allowed us only one hour.

Einstein:
We will see. Oh, I know what you are thinking. In my public statements I have always said that what is essential for a man like me is *what* he thinks and *how* he think, and not what he does or experiences. However, since I have written my autobiography about ten years ago, *Out of my later years*, I have been reading the biographies of many scientists. Now I want to know more than their works, I want to get to know them as human beings. I know now that the work of a scientist is inextricably connected to his life and personality.
But, wait...
First let me divert you for a moment. I must show you my birthday present!
He goes to the table.
Einstein is seen taking what looks like a curtain rod, about five feet tall, at the top of which was plastic sphere about four inches in diameter. Coming up from the rod into the sphere was a small

plastic tube about two inches long, terminating in the center of the sphere. Out of this tube came a string with a little ball at the end.

Einstein:
You see, this is designed as a model to illustrate the equivalence principle, which is the basis of the general theory of relativity.
The little ball is attached to the string, which goes into the little tube in the center and is in turn attached to a spring. The spring pulls on the ball, but it cannot pull the ball up and into the little tube, because the spring is not strong enough to overcome the gravitational force which pulls down on the ball.
A big grin spreads across his face and his eyes twinkle with delight. There is a large drawing that can be shown to the audience. Einstein goes to the drawing and explains.

And now the equivalence principle.
Grasping the gadget in the middle, he thrusts it up until the sphere touched the ceiling touches the ceiling.
And now I will let it drop. According to the equivalence principle, there will be no gravitational force. So the spring will now be strong enough to bring the little ball into the plastic tube.
He suddenly lets the gadget fall freely, and vertically guiding it with his hand, until the bottom reaches the floor. The plastic sphere is now at eye level. Sure enough, the ball rests in the tube.

Dr. Cohen:
Very clever and instructive.
It reminds me of one of the ‘discrepant events” demonstrations my college physics Professor performed. He had a helium balloon attached to the floor of his car and asked a number of students to take a ride with him. The question was: as the car accelerates, which way will the balloon move? This turned out to be very counterintuitive.

Einstein:
There! You have found a perfect use for the birthday balloon.
He stops and thinks a little.

But I think I know what will happen. Newton, of course could have never tested this in his time.
Dr. Cohen takes the balloon and shows what would happen if it were attached to the floor of a car and the car were accelerated.

Einstein:
Wonderful! One way to interpret the strange effect you are describing is to say that the balloon cannot distinguish between acceleration and gravity......Good to hear that this central idea of the general theory of relativity is discussed in physics classes. It should really be discussed much earlier, so that students have time to think about this important principle, and others like it.
Anyway, ... we should now return to where we were when I so rudely interrupted you.
Where were we?

Dr. Cohen:
I remarked that it is interesting that in the history of science great questions seem to be resolved, only to see them reappear in a new form.

Einstein:
Oh, yes. When I was a young man the study of the philosophy and the history of science was considered a luxury and most scientists paid no attention to them. Tell me about your training and why you study the life and works of the great Newton.

Dr. Cohen:
My training is in physics and my research is in the history and philosophy of science. I have taught physics at the university level for a number of years. My specific interest, however, is in the origin of scientific concepts and the relation between experiment and the creation of a scientific theory.

Why Newton? Because what always impressed me about Newton was his dual-genius - in pure mathematics and mathematical physics, as well as in experimental science.

Einstein:
I have always admired Newton: In one person he combined the experimenter, the theorist, the mechanic, and, not least, the artist in exposition. What I have found especially attractive in Newton was his own awareness of the weaknesses in his theories.

Dr. Cohen:
*Dr. Cohen looks at Einstein and smiles***.**
Professor Einstein, you seem to have a most idealized picture of Newton, as a man, a human being. Therefore, I must warn you that historians of science have recently come to the conclusion that Newton was arrogant, tempestuous, and unable to cope with any kind of criticism. He certainly did not suffer fools gladly.

Einstein:
I am sorry to hear that. But that does not take away from his extraordinary achievements.

Dr. Cohen:
Of course not.

Einstein:
On what precisely is this picture of Newton, the man, based?

Dr. Cohen:
Primarily on the details of his scientific battles with Robert Hooke, and others; with Leibniz, for example.

Einstein:
I have always regarded his scientific work as the work of a towering genius, and I saw in my mind a kind, understanding and modest man. But I could never understand why he devoted so

much time to theological and alchemical studies. Why did he not simply reject those theological views he found untenable and assert his own?

Dr, Cohen:
We should remember, though, Newton sealed these private speculations in a box, never to be published.

Einstein:
I am glad to hear that. A man has a right to privacy, even after his death.

Dr. Cohen:
His battles with Hooke and Leibnitz were, of course, well known and have become legends. Newton seems to have devoted much time and energy to advancing a chronology of his discoveries that would place many of them at an earlier date than the primary historical documents would warrant.

Einstein:
Why would Newton do such a thing?

Dr. Cohen:
The reason for presenting this imaginary chronology must have been to date his discoveries sufficiently early to ensure the primacy of these discoveries. We know that some of his well known claims are questionable. For example, his claim that he discovered the inverse square law of gravity as early as 1666, when he was 22 years old, is certainly a fabrication.

Einstein:
Alas, that is vanity.
There is a momentary silence.

Let us go back to Newton, the physicist.

Dr. Cohen:
A good idea.
Of course, it may have been easier for Newton to be all of those things, mathematician, theoretician, and experimenter, in his day. You yourself said in the introduction you wrote to a new printing of Newton's *Opticks:* 'Fortunate Newton, happy childhood of science!'

Einstein:
To a certain extent you are right. As the great mathematician and astronomer Pierre Laplace said: "Newton was fortunate because there is but one universe and it can happen to but one man in the history of the world to be the interpreter of its laws".

Dr. Cohen:
But I believe the essence of Newton's revolutionary science is to be found in what I like to call the "Newtonian style". Newton moved in an ongoing contrapuntal alternation between mathematical constructs and the empirical world. This dynamic relationship is illustrated by how

Newton treated Kepler's laws in the *Principia*.

Einstein:
Yes. His methodology, what you call the "Newtonian style" has left a mark on my work also. We might discuss that in more detail later. It is only in the quantum theory, however, that Newton's differential method becomes inadequate, and indeed strict causality fails us here.
He stops for a moment:

But the last word has not been said.
He stops for a moment and then says loudly:

May the spirit of the "Newtonian style" give us the power to restore unison between physical reality and the profoundest characteristics of Newton's teachings, namely strict causality.

Dr. Cohen:
By causality you mean the kind of predictability we have when the return date of Halley's comet was predicted in his lifetime?

Einstein:
Yes.
Unlike Newton, who made great contribution to mathematics, I understood already as a young man, that I could never become a successful mathematician: I did not have the "nose" to sniff out what was important in the field. You must remember that by 1900 mathematics was a vast field that only Henri Poincare and maybe David Hilbert could securely navigate.
He stops for a moment, plays with his pipe and continues:

However, I soon realized that in physics I had the gift to sniff out what was important**.** I was lucky**.** I managed to concentrate on what was important and follow up on that with the stubbornness of a mule.

Dr. Cohen:
You were clearly able to do this when you wrote your papers in 1905, although this was not recognized for a while.

Einstein:
Yes. As a young man, I saw three areas that needed clarification. An empirical proof for the existence of atoms; a new way of looking at electromagnetic radiation to explain such phenomena as the photoelectric effect; and finally, a new kinematics and dynamics in answer to the intolerable asymmetries when we apply Maxwell's equations in phenomena like the Faraday electromagnetic induction.
I hope I can later demonstrate this well known phenomenon with our simple apparatus on my desk.
He points to the solenoid, magnet and galvanometer apparatus on the table.

Dr. Cohen:
Thank you, Professor Einstein, but what I really would like to do now is explore with you the relation between experiment and theory, comparing Newton's work with yours. Guided by that theme we should touch on all those areas that you discussed in your 1905 paper.
We will also have to discuss your general theory of gravity, of course, because it is an extension of Newton's work.
Indeed, your theory reduces to Newton's for small values of gravity.

Einstein:
Yes it does— as I expected it would. That was actually an important test of the "goodness" of my theory. Clearly, we will not have enough time for all that. But let us try anyway.

Dr. Cohen:
Thank you.
Many people do not realize that Newton was also a great experimenter. Textbooks present the laws of Newtonian mechanics as if they had suddenly appeared to the mind of the great man full-blown, shortly after the apple fell on his head.
Einstein laughs heartily.

Einstein:
That is partly the fault of the way textbooks present physics, I think. I am also misunderstood when it comes to the role experiments played in my work. Most people know only my special relativity theory and then only in terms of one result, namely that $E = m c^2$. But for those who have studied physics, this is just one of the consequences of the two assumptions of the theory. In fact all predicted consequences of the special and most of those of the general theory of relativity (as far as I know) have been empirically (experimentally?) confirmed.

Dr. Cohen:
One should always emphasize that a good theory of science is able to make daring predictions (as the philosopher of science Karl Popper recently so aptly observed) that can be confirmed but are also potentially falsifiable.

Einstein:
I agree. I am acquainted with Popper's work. Actually, he uses the consequence of the general theory of light, the bending of light, as a good example of a daring prediction. But we will probably discuss that later.

Dr. Cohen:
I hope so. But let me see if I can recall the testable consequences of your special theory of relativity and when they were first confirmed. First, the apparent mass increase of a high speed particle were first determined by Bucherer around 1910, using J.J. Thomson's electron tube set up. Secondly, time dilation and the corresponding length contraction was finally confirmed in the mu-meson experiment in the late 1930s. Finally, the last consequence was that $E = mc^2$, as you argued in your short addendum to your relativity paper of 1905. You suggested that perhaps the radiation from radium salts might be able to show this effect. Many years later, of course, the atomic bomb was developed which destroyed Hiroshima and Nagasaki in 1945.

Einstein:
And the peaceful use of nuclear energy.
Good. It is generally accepted that the consequences you described have all been experimentally confirmed.
Einstein seems to remember something.

But you know, when Leo Szilard came to me with that now famous letter he wrote to President Roosevelt in 1939, that was the start of the Manhattan project to develop a nuclear bomb, I really did not think that it was possible. But I signed the letter anyway.
He pauses.

I wish it had never been possible.

Dr. Cohen
Well, it was inevitable. ...
There is a pause. Dr. Cohen changes the topic.

Professor Einstein, textbooks seem to suggest that your work in both the special and general theory of relativity rests mainly on your clever thought experiments. It is often emphasized that you were not an experimenter, but did all your work with pen and paper.

Einstein:
That is unfortunate. You must remember that I was connected with and intimately acquainted with experimental work in physics, first through my independent studies at the ETH in Zürich, and later through my daily work at the Patent Office in Bern. I worked there as patent clerk between 1901 and 1908, assessing new inventions, especially in electromagnetic mechanisms.

Cohen:
So you are saying that your intimate acquaintance with experiments was a necessary bu not sufficient condition for your theoretical work.

Einstein:
Yes, I do. Actually, I believe that if it had not been for this intimate contact with experience, I could not have written those fruitful papers 50 years ago.
Let me also add here that it may have been a stroke of luck that I was unable to secure a teaching position at a university. The constraints placed on Professors (especially young Professors) by the requirements of teaching and publication may have not been conducive to original work.

Dr. Cohen:
But I seem to recall a quote attributed to you. You are asking the question: “Can human reason discover the properties of real things by thought alone, without the help of experience?”

Einstein:
The answer, of course, is that we can go far with what I call ‘the free play with ideas’. But I do not think that Descartes-like program of rational physics is viable. The ultimate test is always nature.

There is a pause and Einstein looks around, goes to the desk to pick up another pipe makes himself comfortable. There is a pause of about a half minute.

Dr. Cohen:
Turns to the audience.

Ladies and gentlemen, we will take a few minutes rest. This will give you a chance to frame some questions for later.
He goes to Einstein and they quietly talk, looking at the display of the apparatus on the table.

SCENE 2
Dr. Cohen:
Turns to Einstein and says, speaking slowly:
Professor Einstein. I, too, have a very special gift for your birthday, although a little belated.
Einstein looks up surprised and smiles.

I have managed to contact Isaac Newton and we will have the pleasure of his company in a few moments. I have had a preliminary talk with him and he is willing to discuss with you his ideas and how you think they relate to yours.
Einstein looks up and is visibly astonished, but his face soon relaxes.

Einstein:
Well, now this is a surprise. I will not ask you how you managed to do this, I will simply try to compose myself a little.
He looks a little puzzled but soon relaxes.

Let’s see. According to the special theory of relativity it would be possible to travel into the future, but not back to the past. In other words, according to my theory, it would be impossible for me to travel back to Newton’s time.
Newton arrives. He walks slowly, looks around the room, stops and briefly surveys the instruments displayed.
Dr. Cohen gets up and greets Newton.

Sir Isaac, may I present Professor Einstein.

Newton:
Thank you, Dr. Cohen, the pleasure is all mine, Professor Einstein. Finally, we meet.
He turns to Einstein. Einstein holds out his hand.

Einstein:
Welcome to Princeton, Sir Isaac. This is a wonderful occasion for an old physicist to finally meet the great Newton. I hope you had a pleasant journey.

Newton:
Remember, I am much older than you are, but somehow the cosmic trip invigorated me. Traveling through the cosmos was certainly more pleasant than traveling in a carriage in the beginning of the 18th century.

Einstein:
What are your first impressions, Sir Isaac?

Newton:
Very pleasant. But it is a "culture shock", to use a 20th century expression, to arrive in North America, almost three centuries after my time. In my time this was a British colony. Even though I have been aware of the products of modern technology, to actually see these mechanical carriages you call cars move around, carrying people everywhere at high speeds, is truly awe-inspiring.
He laughs.

Tell me, do these fast mechanical contrivances go by themselves, or are they driven by someone?

Einstein:
People drive them, Sir Isaac. I myself do not know how to drive a car, although I am a physicist who, like yourself, is acquainted with the study of time and the physics of high speeds.

Einstein:
He pauses briefly and then says with emphasis:

But for us physicists, the distinction between past, present, and future is only a stubbornly persistent illusion.
Don't you agree, Sir Isaac?

Newton:
Well, this experience certainly makes it sound plausible.
Newton pauses and then continues:

I would think that being daily confined in a car, a train or even airoplane, to both inertial and accelerating frames of reference, everyone now intuitively understands my laws of motion.

Dr. Cohen:
You will be surprised to learn, Sir Isaac, that neither your laws of motion nor Professor Einstein's central ideas of his relativity theory are now or indeed will be well understood by the general public in the 21st century.

Newton:
Your first claim is difficult to understand but your second I can well understand myself, having thought about Professor Einstein's ideas during my cosmic journey.
Newton walks to the balloon, pick s it up and then suddenly realizes that if he lets it go it will rise. He smiles:

There were no balloons in my time, although the ingenious Robert Boyle or the clever Robert Hooke could have invented it. But, somehow, the idea of buoyancy in the atmosphere was not in the air, so to speak.
He looks at the balloon and smiles.

This is truly a marvellous thing: a lighter than air object that floats in air and obeys Archimedes' law of flotation.

Dr. Cohen:
Sir Isaac, we were just discussing how it is possible to illustrate the equivalence of inertial and gravitational mass. You attach the balloon to the floor of a car and watch what happens when the car accelerates. Remember the car is completely closed.
Newton goes to the blackboard and draws a picture. He thinks for a moment

Newton:
Yes, wonderful. A most unexpected effect, that can only be explained by the equivalence principle. Perhaps you can demonstrate this to me later, Professor Einstein?

Einstein:
Unfortunately, Sir Isaac, I have never learned to drive a car. But our young friend here could perhaps take us for a ride in his car later.

Dr. Cohen:
I would be happy to do this.
He turns to Newton:
But you tried to show this equivalence using pendula, Sir Isaac.

Newton:
Indeed, I did. Well, not quite. I used different masses on pendula to show that inertial and gravitational masses are equivalent, at least within the error of measurement I was able to achieve.
He picks up Einstein's 'ubiquitous pendulum'.

Actually, I used two very long pendula of identical length, containing hollow boxlike bobs, a the center of which I placed equal amounts of nine different substances. Thus I showed that their weights were proportional to their quantities of matter.

Newton walks to the desk and picks up the pendulum. He demonstrates what he measured and briefly explains his conclusions.

Dr. Cohen:
It is interesting, Sir Isaac, that the modern reference to inertial and gravitational mass, what you called quantity and weight, is due to Professor Einstein's work.
One of our famous scholars, Professor Westfall, who studied your work for many years, once wrote that "It is safe to say that without the pendulum there would have been no *Principia.*
Would you agree?

Newton:
Well, permitting a slight exaggeration, I would agree. When I finally wrote down my three laws of motion in the *Principles of Philosophy,* I had to decide how the notion of force fits into three distinct classes. One was *free fall,* the other *collision*, and the third the puzzling phenomenon of *centripetal force*.
Newton uses the pendulum to demonstrate these three cases: free fall, centripetal acceleration, and collision.

Einstein:
That was a very clear demonstration, Sir Isaac. I wish my physics teacher had been that clear when I first learned your laws of motion.

Dr. Cohen:
But according to Professor Westfall you had great difficulty in defining inertia and in separating the concepts of centrifugal and centripetal force.

Newton:
Well, young man, I assure you the laws of motion, as I published them in the *Principia,* did not come to me full-blown, right after the apple fell on my head, as most people seem to think.
Both Einstein and Dr. Cohen are smiling.

I had real difficulties in moving from the concept of impetus to that of inertia. It was even more difficult for me to move from the idea of centrifugal (center-fleeing) to the concept of centripetal (center seeking) motion of the planets.
He again demonstrates the difference using a pendulum. He holds the pendulum above his head to do this.

Einstein:
But we must be clear on this. The equivalence of inertial and gravitational mass was for you an experimental fact. But in my theory of relativity it became a logical necessity.
*He stops for a few seconds to make sure that this point is duly noted***.**

I think that your most important idea was the recognition of the equivalence of rest and constant velocity, that is, that there is no difference between rest and motion of constant speed in a straight line. Further, your distinction between mass and weight and the recognition that a mass has two separate and distinct aspects, one due to acceleration (inertia) and the other due to the body’s response to gravity, was important.

Dr. Cohen:
The story of how you calculated the period of the moon, as you have just explained it, is enshrined in all the textbooks. However, we historians now do not understand how it was possible for you as early as 1666 (when you were 22 years old), to have made those calculations. The reason we are puzzled is that, according to our research, you did not have the concept of centripetal acceleration firmly in place at that time.

Newton:
I remember, I think it was 1697, that I wrote about the apple falling from a tree that made me think of universal gravitation. It was occasioned by the fall of an apple, as I sat in a contemplative mood. .
That was also the occasion for thinking about gravity extending to the moon.
At that time I also wrote about my early calculations of the period of the moon based on the inverse square law.
He stops for a moment and then continues...

The first story is true, the second one, however, is a slight exaggeration. I admit, it was not until about 15 years later, in 1677 I believe, when I made those calculations.
He stops for a moment.

Why did I report the earlier date?
I suppose, I was motivated by a touch of vanity; I tried to ensure the primacy of my discovery and the successful incorporation of the inverse square law into a coherent system.
He becomes quite and in a low voice continues. He looks at Dr. Cohen.

My problem with Hooke, as you know, was simply the result of his making unwarranted claims and unreasonable demands for recognition. Had he been more modest, I would have gladly obliged.

Einstein:
Sir Isaac, also in my time many scientists have suffered from vanity. I, too, have displayed vanity on occasion. You know, it had always hurt me to think that Galileo did not acknowledge the work of Kepler. He stubbornly clung to Copernicus' circular orbits. That was clearly a display of vanity.
He stops for a moment, and then continues reflectively:

But I think, vanity comes in many forms. When a man says he has no vanity, this in itself can be seen as vanity, because he took such special pride in the fact.
Everyone smiles. Dr. Cohen turns to Newton.

Dr. Cohen:
Thank you for your frank answer, Sir Isaac. I do not think this confession will change the history of science, nor take away from your extraordinary achievement. But let me press you a little further...
Newton put out has hand as if to stop Dr. Cohen.

Newton:
Young man, let me anticipate your question. Is this about Robert Hooke's letter, in which he suggested to me, before I wrote the *Principia*, that the motion of the moon around the earth is a composition of inertial motion and a centripetal acceleration? And further, that the centripetal acceleration in turn is produced by gravity which is inversely proportional to the square of the distance? Why did I not acknowledge his contribution?

There is a silence of several seconds. Newton looks a little embarrassed, but quickly recovers and then smiles.

Newton:
Well, I will make a long story short. Indeed, this was an unpleasant relationship. It is true that Hooke was a gifted man with many diverse talents. He was also a good mathematician and geometer. Well, at least he was competent.
When he gave me the idea of compounding inertia with centripetal acceleration to calculate the period of the moon, I immediately recognized that he was right. But when he later demanded my acknowledging him as the discoverer of the inverse square law I refused even to pay tribute to his original suggestion.
He stops and looks a little angry. He goes on, raising his voice.

Hooke had done no more than glimpse this important law obscurely from a distance. He did not understand the essence or the implications of this central law.
He stops for a moment and then continues.

It is one thing to have a good idea, but quite another to be able to incorporate it into a larger coherent theory.
\Einstein gets up and approaches Newton, he puts his hand on his shoulder and speaks in a kind soft voice.

Einstein:
Sir Isaac**,** let me assure you, I have had the same problem with my paper of 1905 on relativity theory. In that paper I gave no references at all. Rather vain and presumptuous of a 26 year old obscure patent officer who was writing to fundamentally change the world of physics, don't you think?

Newton:
Well, you displayed the self assurance of a first rate mind. I can understand that.
Newton smiles.

Einstein:
Of course, I used Newton's ideas and Maxwell's equations, but I did not think it was necessary to cite references. They were universally known and accepted. However, the question which has been following me all my adult life is based on my committing a 'sin of omission': I failed to mention the famous experiment by Michelson and Morley that gave a null result for the existence of an ether.
Einstein stops for a second or two and then continues:

What I offered in the very first paragraph was the case of a commonplace student demonstration to show that the idea of relativity was everywhere. This is a demonstration that every student is shown to illustrate Faraday's law of electromagnetic induction.
Dr. Cohen, you must recognize this simple demonstration.

Dr. Cohen:
Yes I do. I have puzzled over this passage in you article for a long time. As a physics student I asked myself: How could generations of physicists have missed the message contained in this simple demonstration?

Einstein:
Yes, indeed.
He goes to Dr. Cohen and ushers him to the table.

Dr. Cohen, here is your chance to show Sir Isaac the basic principles involved in this demonstration and why it struck me as a fundamental puzzle 50 years ago that lead me to the special theory of relativity. I will just listen.

Dr. Cohen:
Well, I am glad that I have studied your famous paper and thought about your example.
He turns to Sir Isaac:
Sir Isaac, ... *he explains in detail Einstein's example...Essentially following Einstein's explanation in his paper.*
He goes to the table and picks up a solenoid, a large bar magnet and shows how the solenoid is connected to a galvanometer

Einstein:
Dr. Cohen well done, I could not have done it better.

Newton:
Thank you, Sir.

Einstein*:*
Gentlemen, I have been waiting for an appropriate moment to momentarily stop your energetic conversation.
I will go into the kitchen. Frau Dukas has prepared coffee and tea for us.
Please take a break. You deserve it.
Einstein leaves and the two continue talking in a low voice.
Einstein returns with a tray.

Einstein:
Gentlemen. There is coffee and tea. Coffee for me and tea for Sir Isaac?
What do you drink, Dr. Cohen?

Dr. Cohen:
We Americans are mostly coffee drinkers.
The three help themselves to coffee and tee.
Meanwhile Newton and Einstein drink their coffee and tea. They get up, go to the blackboard and seem to discuss a problem. Einstein draws a sketch. They have a chat that cannot be distinctly heard.
Dr. Cohen steps toward the audience and speaks slowly.

Ladies and gentlemen. We will give you a chance to relax for a few minutes.
This will also allow you to prepare questions that, if time permits, you can direct to our eminent scientists.
He moves slowly toward the two at the blackboard and listens to their conversation, allowing about two to three minutes for the audience to relax and recuperate.
The three return and assume their previous positions.

Einstein:
Well, I am really quite revived.
Now, where were we? Oh, yes. We looked at the Faraday's apparatus.
How should we proceed? Dr. Cohen, what is your suggestion?

Dr, Cohen:
Gentlemen: I would like to propose the following for the rest of the evening: First, let us look at the three papers of Professor Einstein that set the tone for the new physics in 1905 in some detail. How are the central ideas of these papers connected to Sir Isaac's work? Then we could conclude by looking at the general theory of gravity, the basic assumptions involved , the predictions made and their empirical confirmation. Again we could ask the question: How are the central ideas of these papers connected to Newton's work?
He looks at Einstein and continues:
Professor Einstein, can we start with you?

Einstein:
Yes, this is a good idea. But I do not think we will be able to say everything today.
He pauses for a moment.

In my paper on Brownian motion I tried to show how we can use small particles (of the size of about 10 times the wavelengths of light) that there are atoms. Even as late as 1905 there were noted physicists who did not believe in the reality of molecules and atoms.

Newton:
In my private speculations, I tried to build a theory around the phenomena of light and electricity, as well as the forces that hold corpuscles together in matter. I even tried to infer from what you call interference and diffraction phenomena the size of corpuscles of matter.
There is a momentary lull. Dr. Cohen leans toward Einstein.

Dr. Cohen:
And your second paper, Professor Einstein?

Einstein:
In this paper, which I immediately recognized as the most revolutionary of the three, I proposed what I called a *heuristic*. In other words it was an informed guess. I proposed that electromagnetic radiation, which includes light, interacts with matter in well defined quanta of energy, or as you, Sir Isaac, might call corpuscles of energy.
He pauses and then continues

This hypothesis was able to account for the phenomenon of the photoelectric effect, well established by experiments already in the late 19th century.
Dr. Cohen looks at Newton.

Newton:
What are quanta? Are quanta just another name for my light corpuscles?

Einstein:
In a sense, yes. But there is a quantitative and qualitative aspect to my quanta that is not suggested by your light corpuscles, Sir Isaac.

Dr. Cohen:
Sir Isaac: When light of high frequency and low wavelength (ultraviolet) impinges on a metal like Zinc, the plate becomes electrically charged and a simple electroscope can be used to show that it becomes negatively charged.....

Professor Einstein received the coveted Nobel Prize in 1921, the citation referring to his general contribution to theoretical physics but also specifically mentioning his explanation of the photoelectric effect. It is interesting to note that the paper only devotes two pages to the photoelectric effect.

Newton:
Is there a simple demonstration to show this effect?

Einstein:
I think the best way to demonstrate this effect is use the simple apparatus of Heinrich Hertz. I like this because it is simple and can be demonstrated in a class room.
He goes to the black board and describes the experiment. He also writes down his famous photoelectric equation.

Newton:
That is very convincing. But it is not obvious to me that your equation is necessarily connected to a corpuscular theory of light that you call quanta.

Einstein:
I say this in all modesty, Sir Isaac: It was obvious to me, but not to the majority of physicists, including Planck.

Dr. Cohen:
Sir Isaac, you espoused a corpuscular theory of light and I think you had difficulty in explaining the interference rings shown by your often cited interference patterns found in “Newton’s Rings”. But you found it difficult to explain the kind of interference shown here using your corpuscular theory.
He goes to the table and picks up the “Newton’s Rings” apparatus and gives it to Newton.

Newton:
Yes. I could not explain interference very well with my corpuscular theory. So I did try to blend my corpuscular theory with the wave theory of Huygens. But, I must admit this was not easily done.
He describes the interference effect demonstrated by the lens (with a large radius) sitting on a sheet of glass.

I know I advocated the corpuscular theory of light, but I always recognized that light was also a periodic phenomenon. I was forced to postulate waves as a sort of concomitant of the corpuscles in the ether. But, again, I could never accept the idea that these waves constituted the light itself!

Einstein:
This is very interesting, Sir Isaac. Your unwillingness to accept the wave theory of light to replace your corpuscular theory, reminds me of Planck's unwillingness to accept the quantum theory of light, although he was forced to use the idea of quanta, or what we might call light corpuscles in explaining blackbody radiation. Like you, he saw his quantum explanation as a concomitant of the wave theory.

Newton:
Well, I thought that particles of light effect a medium like glass or water the same way as a stone thrown into water can excite waves that continue to spread in the water, long after the passage of the stone.

Einstein:
A very interesting analogy, Sir Isaac.
A pause of a few seconds.

Newton:
I understand that my corpuscle theory of light was finally overturned by Thomas' Young's interference demonstration of 1808 and then later by Foucault showing in 1838 that the speed of light diminishes in water, favouring Huygen's wave theory.

Dr. Cohen:
Well, it was not easy to overturn any of your theories or ideas, Sir Isaac!
Everyone smiles. Dr. Cohen continues.

No sooner had Young's paper appeared than Young became the subject of the most violent and undeserved attacks in science since the seventeenth century.
He looks at Newton:

Your century, Sir Isaac!
Indeed, the budding wave or undulatory theory received a severe setback until about twenty years later with the work of Fresnel.

Newton:
Then what was considered the deciding factor in favour of the wave theory, and the abandoning of my corpuscular theory?

Einstein:
There were two factors. First, the formulation of the principle of interference by Young. And secondly, the *experimentum crucis* of Foucault that the speed of light in water is diminished by a factor of the inverse of the refractive index, as Huygens already predicted.

Newton:
I have always looked askance at claims that an *experimentum crucis* has been found that overturned a theory. I seem to recall that his idea was first presented by Sir Francis Bacon, in the early seventeenth century.
There is a pause

Einstein:
But wait. I just remembered. I have a little toy apparatus that was recently given to me.
I think they call it a radiometer. This little toy is actually based on a very controversial issue that began in the 1870s with the construction of a special tube by the British physicist Sir William Crookes.
He describes the tube in detail.

Now, if you expose it to light the vanes move. But they move the wrong way if you believed in Maxwell's prediction of the pressure of light! Just as puzzling was the fact that when the pressure of the gas inside the tube was very low, the vanes stopped moving!

Newton:
Newton studies the radiometer
This is truly mysterious.

Dr. Cohen:
I can add a little history here, Sir Isaac. The first attempt to explain the Crookes tube phenomenon was based on Maxwell's formula for the pressure of light. Since at very low pressures there was no motion, the explanation then was given based on the kinetic theory of gases.
Turning to Einstein:

The last significant paper that gave a more detailed analysis was given by you, Professor, in 1921.

Einstein:
Yes. The phenomenon fascinated me. Of course, if you could supply a strong enough light source, reduce the friction on the vanes, the pressure of light would be enough to make the vanes move again. But this time the other way around!
Einstein laughs and is obviously delighted.

Dr. Cohen:
Light has a pressure that can be actually measured with a very intense light source. That was established a few years before 1905.

Einstein:
Yes, I believe I was aware of this at the time I published my 1905 papers.
By 1908 I also managed to show theoretically that electromagnetic radiation (which included light) has both a wave and a corpuscular aspect.

Newton:
It sounds like you mixed the wave and particle nature of light, very much the way I did in trying to explain the interference patterns I observed with a thin lens.

Einstein:
Yes. There is certainly a similarity.
But we should also remember that this little apparatus may be looked upon as a toy now, but it produced not only a great controversy in theoretical physics but it also led to the scientific instrument known as Crookes' tube that eventually evolved into the x-ray apparatus of Roentgen in 1995 and two years later into J.J. Thompson's apparatus to discover the electron.
He looks at Newton:

But your speculative effort to blend a wave and corpuscular theory of light was achieved only by the end of the second decade of the 20th century.

Newton:
It is utterly fascinating that a simple apparatus can be the basis for a new way of seeing things as well as making new discoveries. The pendulum in my time was such a simple toy. We have already discussed the importance of the pendulum in my work.
There is a momentary lull.

Dr. Cohen:
Gentlemen, we must go back to our discussion of Professor Einstein's papers of 1905, lest we forget our train of thought.

Einstein:
I agree. But I would really much rather continue our discussion. Perhaps we could come up with another "toy" that changed physics.
Everyone smiles.

Alright then, let us continue. I believe we were discussing my last paper.
This paper was less revolutionary than the one on quanta, but is now considered the most revolutionary and is certainly the most famous. We have already looked at the simple apparatus that illustrates Faraday's EM induction principle.
Essentially I argued for a new kinematics (and dynamics) that connects electrodynamics with mechanics.

To achieve that, I proposed two axioms (postulates) from which I eventually derived the new transformation equations and, most importantly, proposed three experimentally testable consequences.
Einstein's stops for a few seconds and then continues.

The first postulate, which I called the "Principle of Relativity" said that
"The same laws of electrodynamics and optics will be valid for all frames of reference for which the equations of mechanics hold good".

The second postulate states that:
"The speed of light is always propagated in empty space with a definite velocity c which is independent of the state of motion of the emitting body".

Dr. Cohen:
It is unfortunate that students of physics generally memorize these two postulates and have little or no idea where they come from and the reasons for stating them as the basis of a new theory of dynamics.

Einstein:
Of course, I knew that the principle of the constancy of the speed of light was in conflict with the rule of addition of velocities. I remember it well when I had my sudden insight.
It was a beautiful day in Bern and my friend Besso and I were out walking when the idea occurred to me. Discussing the matter with him I suddenly understood it. I immediately left without explanation and hurried home. He must have thought that I went crazy.
Einstein stops and laughs. Then he continues…

Next day in the patent office I thanked him for his assistance in making things clear for me.
Einstein laughs again

Dr. Cohen:
You are keeping us in suspense, Professor Einstein.

Einstein:
Oh yes—my solution was the very concept of time, that is, that time is not absolutely defined. Five weeks later, after a struggle, the theory of special relativity was completed.

Newton:
It seems to me that the axiomatic structure of your physics is not unlike mine was. I also presented postulates (the three laws of motion and the inverse square law of gravity) and from them deuced three immediately experimentally testable consequences. These were the motion of the planets, the tides, and the period of the pendulum.
Einstein nods in agreement. Newton continues.

The first postulate sounds revolutionary but the second postulate is one that was endorsed by Galileo and me. But the second postulate makes absolutely no sense to me.

Newton stops for a moment and then continues with emphasis.
In fact these two postulates seem to be irreconcilable.

Einstein:
It did not make sense to me either in the beginning, Sir Isaac.
But after some years of struggle I came to the conclusion that the simple transformation equations of Galilean-Newtonian kinematics must be replaced by new ones that were consistent with these two postulates. Apologies, Sir Isaac.
Newton nods his head.

My key to reconcile these two was to first banish the existence of an ether, and then insist that time is not absolute, that is, time as measured from one frame of reference was different from the time measured in the other.
Einstein goes to the black board and explains.

I then assumed that the Galilean-Newtonian transformation equations, which are intuitively obvious to everyone, and have been used in all our mechanics and electromagnetic calculations, must be changed. Of course, the time in one frame of reference is now different from the time in another frame of reference
He writes down the simple classical kinematic transformation equations.

There. After a little algebra, using the two postulates of relativity we can easily show deductively that the new transformation equations hold:
He writes down these transformation equations.

Newton:
In my system, as I wrote in the *Principia,* referring to the nature of time: "... absolute, true, and mathematical time, of itself and from its own nature, flows equably without relation to anything external..." Still, I find it hard to believe that it could be otherwise.
Pauses for a moment and then continues.

But, I suppose, there comes a time when we must give up cherished assumptions.

Einstein:
Believe me, Sir Isaac, it was a struggle for me, too, to make this decision about the nature of time. As was for Planck to accept the idea of the quantum of energy, so for me to accept that time is not absolute was an act of desperation.
He stops and then says emphatically:

Unlike for him, though, my step was not an ad-hock decision. The new idea of time was based on the operational definition of the relativity of simultaneity.
He stops and looks reflective:

I was especially aware that this desperate act would change the Newtonian picture of mechanics. In fact I wrote at the time:

“Newton, forgive me, you found the only way which in your age was just barely possible for a man with the highest powers of thought and creativity. The concepts which you created are guiding our thinking in physics even today...”

Newton:
Thank you for the tribute, Professor Einstein. I, too, had to make desperate decisions when I developed my gravitational theory ... the assumption of instantaneous action at a distance, for example.
There is a pause for a few seconds.

Dr. Cohen:
Excuse me, Professor Einstein, but let me just say that these equations were already discovered by the Dutch physicist Lorentz a few years before the publication of your paper.

Einstein:
Yes, you are right. But I was not acquainted with these until later. Actually, in 1900, the British physicist Larmor, already anticipated Lorentz’s work, formally obtained the transformation rules for space and time under which Maxwell’s equations remain exactly invariant.
Einstein stops for a moment and then continues:

However, the difference between my method and that of the great Lorentz is that I deduced them from the two postulates deductively and, most importantly, found that it was superfluous to assume the existence of an ether.

Newton:
What was the reasoning of Lorentz when he proposed these transformation equations?

Einstein:
Lorentz proposed these as, what we might call, a “protective hypothesis”, to explain the apparent length contraction required to understand the null results of such experiments as the Michelson-Morley. The assumption of the ether also demanded a length contraction for electron motion in electromagnetic fields guided by Maxwell’s equations.
He stops for a moment
Lorentz thought the electrons actually changed shape physically!

Dr. Cohen:
Sir Isaac, the Michelson-Morley experiment was performed in the 1880s. They showed that the speed of light remains constant, as measured with the motion of the Earth and against the motion of the Earth. In other words, the experiment seemed to strongly suggest that there was no ether.

Newton:
I cannot imagine the propagation of light without a medium!
He thinks for a moment and then continues.

But going back to your axiomatic system: You are then saying that these equations in your system came from a solid theoretical basis, whereas Lorentz divined them, as it were, in order to protect classical (dare I say Newtonian?) mechanics and the existence of an ether?

Einstein:
Yes, exactly. But that does not take away from the excellent work of the great Lorentz. Actually, one could say that for Lorentz they were equations of transformations which make the equations of the electron theory covariant; for me, they were the expressions for the general properties of space-time.

Dr. Cohen:
We must not forget that these famous equations are still called the "Lorentz transformations". Sometimes they are also called, as they should be, "The Lorentz-Einstein transformations".

Newton:
Does that mean that when we compare the relative velocities **V** of two objects, say $\mathbf{v_1}$ and $\mathbf{v_2}$ the relative velocity is not $\mathbf{v_1 + v_2}$ **?**

Einstein:
Precisely, Sir Isaac.
Einstein goes to the Black and explains.
In the new kinematics we have the transformation:

$$\mathbf{V = (v_1 + v_2) / (v_1 + v_1 v_2 / c^2)}$$

rather than the simple $\mathbf{V = v_1 + v_2}$ **,** that is intuitively understood by everyone.
Please notice that when we find the relative velocity of two cars, one moving east at 100 km/s and the other west at 100 km/s is still 200 km/s. That is so because the last factor is vanishingly small.

Dr. Cohen:
Excuse my interruption, Professor.
Einstein smiles and nods.

Sir Isaac, you can see that in the limiting case when the speeds are c, their relative velocity is still c!

Newton:
That looks more like a mathematical trick, at least at first sight. But this new kinematics does not really change the intuitive formula of addition for velocities that are still very high, in fact higher than any relative velocities we encounter even in astronomy
He stops and thinks for a moment.

I believe the highest relative velocities we can imagine in the solar system is about—let me use your measure of kilometers—about 100 km/s. For example, Haley's comet at perihelion, the closest approach to the sun.

Your relative velocity formula would only change it by a small amount which could not be measured.

Einstein:
You are right, of course. But we have very high velocities in galaxies receding from us and the little charged corpuscles we call electrons can be accelerated in the laboratory to almost the speed of light. Here Newtonian mechanics breaks down.

Newton:
It is good to hear that my laws of motion are still valid, at least for engineers, space travel, and sporting events.

Dr. Cohen:
Newton still reins supreme for velocities as high as ... high as ... 1/10 the speed of light!
He stops for a few seconds, looks at Einstein and then continues:

I think, Professor Einstein, you can now discuss the other consequences of your theory.

Einstein:
Yes. There are actually only three consequences, beyond the new addition of velocities we just discussed: time dilation, length contraction, and apparent mass increase. Notice that
I have not included the mass energy equivalence, captured by the equation $\mathbf{E = mc^2}$, so well known to the public.
He stops for a moment and then continues emphatically.

Actually, it is not necessary to experimentally confirm all three, the confirmation of one necessarily implies the other two!

Dr. Cohen:
Let us give Professor Einstein a little time to relax. I will quickly review the history.
He looks at Einstein and sees Einstein giving him an affirmative look.

All right then. The paper on Brownian motion inspired the French physical chemist Jean Perrin to design clever experiments to calculate Avogadro's number. So by about 1910 even the chemist Oswald conceded and accepted the existence of atoms.
Einstein leans over and interrupts.

Einstein:
Yes. Publicly. But privately I doubt that he was convinced.
Dr. Cohen smiles.

Dr. Cohen:
The second paper about the quantum nature of light had a much rougher fate. The explanation of the photoelectric effect in that paper was not accepted until about 10 years later. The American physicist Robert Millikan, who finally showed that Einstein's simple formula worked, insisted until about 1920 that this experimental confirmation did not necessarily mean that Einstein's

quantum hypothesis was correct. He argued that there were a number of classical theories around that gave the same result.

Newton:
I agree. The confirmation of a single equation does not mean that the underlying theory is correct.

Einstein:
I remember being a little upset about the refusal of Millikan to accept the quantum hypothesis background to my equation. But I realize, certainly realize now, that what Sir Isaac is saying, is true.
Stops for a moment and then continues:

And let us not forget that there was a high price to pay for the acceptance of my quantum hypothesis, namely the abandonment of the entire electromagnetic wave theory of light.
Even Planck could not accept it in the beginning. Scientists do not like giving up a trusted theory.

Dr. Cohen:
Of course there was also great resistance to the paper on relativity. The paper was not even mentioned in the next issue of the *Annalen der Physik*

Einstein:
But this time Planck was the only physicist that responded to me in 1905. The question was: Is Einstein's theory just another version of Lorentz's electron theory?
The turning point came when my mathematics teacher at the ETH, Hermann Minkowski "mathematized" my work, in 1908. In his lecture in Cologne in 1908 he uttered the now famous words:
"Henceforth space by itself, and time by itself, are doomed to fade away into mere shadows, and only a kind of union of the two will preserve an independent reality"

Dr. Cohen:
Was he not the one who reprimanded you when you were student at the ETH, by saying:
"Einstein, you are a clever fellow, but you are a lazy dog!"
Einstein laughs.

Einstein:
Yes. Since the mathematicians have discovered my theory and reworked it, I do not understand it any more.

Newton:
Gentlemen, I am sorry, but I think this Minkowski exaggerated a little. How can he relegate the Newtonian universe to the fate of a mere shadow when it has been - and still is -such and important part of physics and engineering!
Newton pauses for a while then continues...

But I can understand your response to the mathematicians working on your theory of relativity. In my later years I found Leibniz's work, and the work of Johannes Bernouli, the young Euler's reworking of my equations of force, and especially the mechanics of Lagrange, difficult to understand.
He stops and then says with emphasis:

Lagrange banished the central concept of my dynamics, namely that of force, completely!

Einstein:
But don't forget, Sir Isaac, the Lagrangian formulation of mechanics is just another way of expressing the Newtonian dynamics!
Newton nods in agreement.

Not until about 1915 was the special theory of relativity generally accepted. And I regret to say the great Lorentz and even Mach never really accepted it.
Einstein stops and seems tired. Dr. Cohen and Newton exchange glances.

Dr. Cohen:
Professor Einstein, perhaps we should stop here. Frau Dukas will be angry if you become tired.
Einstein emphatically gestures with his hands:

Einstein:
No, no! Please, not yet. Frau Dukas will understand.
Let us discuss my general theory of gravity a little. After all, the theory is an extension of Sir Isaac's work.

Dr. Cohen:
All right, but not too long, please. I promised Frau Dukas.
Einstein smiles and continues

Einstein:
Let me start our last topic, the general theory of relativity, by saying that it is ironic that the now famous formula $\mathbf{E = mc^2}$ **,** which appeared in a later addendum of three pages to my relativity paper, was only an afterthought to my paper. That short note had a title in the form of a question: "Does the Inertia of a Body Depend on its Energy Content?". The formula should be seen describing the general connection between energy and inertial mass.

Dr. Cohen:
This aspect of the formula is not generally recognized and understood by most people.

Einstein:
Unfortunately you are right.
It soon became clear to me that the special theory is only the first step toward a more inclusive theory that also contained gravity. I also remembered the torsion balance experiments of Eotvos, following Sir Isaac's first excellent attempts to show that the gravitational mass of a body is exactly equivalent to its inertial mass.

He turns to Newton:
How accurate were your findings, Sir Isaac, using pendula?

Newton:
If I remember correctly, I found it accurate to about 1 part in 1000.

Einstein:
That was very good, using your, forgive me, simple method. The Hungarian physicist, Roland Eotvos, using very delicate torsion balance methods, found it accurate to 1000 of that.

Newton:
That is, of course, much better. But was it necessary to go beyond my experiments?

Einstein:
Probably not. My story, or epiphany, on the other hand, is well known to physicists, but is not generally known by the public.
Pauses for a moment and then continues.

The story of the falling of an apple and you Sir Isaac, sitting under the tree and contemplating a full moon in the sky, is a very compelling image. I am afraid my story is not as compelling.

In November of 1907, while working on a paper on the SRT, I tried to modify Newtonian theory of gravitation in such a way that its laws would fit in the special relativity theory.
I was sitting in the patent office at Bern when suddenly I had the 'happiest thought of my life' in the following form. The gravitational field has only a relative existence in a way similar to the electric field generated by electromagnetic induction (Italics added). Because for an observer falling freely from the roof of a house there exists—at least in his immediate surroundings—no gravitational field. Indeed, if the observer drops some bodies then they remain relative to him in a state of rest or in uniform motion. The observer therefore has the right to interpret his state as 'at rest'. Because of this idea, the uncommonly peculiar experimental law that in a gravitational all bodies fall with the same acceleration, attained at once a deep meaning\

Newton:
I like your story very much, Professor Einstein. The story of the falling apple is well known. But do people understand the ideas and concepts that followed? Perhaps the story about falling from a roof—unto a haystack, perhaps—may become as famous in the future.

Dr. Cohen:
Professor Einstein, I am reminded of your now famous book with Leopold Infeld that you wrote in the late 1930's for the general public about your two theories of relativity. Here you describe a thought experiment, that has since become famous. May I describe this thought experiment?

Einstein:
Oh, yes, I remember being asked to write a book about both relativity theories for the general public. Luckily I managed to persuade the Polish mathematician Leopold Infeld, who was at Princeton at the time, to collaborate with me.

Dr. Cohen goes to the blackboard and makes a sketch of two elevators, one on earth and the other in space.

Dr. Cohen:
Professor Einstein, I took a little liberty with the original version of your thought experiment. This is how I used to present it to my physics classes:
Imagine two elevators, one on earth and the other in deep space, where the effect of gravity is negligible. The elevator on earth is at rest, relative to the earth, and the elevator in space is accelerating with an acceleration that matches the value of g on earth. Physics students are doing identical experiments in both elevators and are communicating with each other, being able to do so instantly. They perform experiments like: testing free fall, finding the period of a pendulum, the period of a spring; they even find the bending of light using a light beam. According to Einstein's equivalence principle, their results should be identical. Is there really no experiment that could be done to tell the physics student where she is?

Einstein:
I am sure that this thought experiment elicited good responses in your classes.

Dr. Cohen:
Yes. I have never had any problems with students not understanding this thought experiment. It is certainly more accessible to them than the thought experiments in your special relativity paper.

Einstein:
Yes. I am sure you are right.

Newton:
So far I am with you...

Einstein:
As described in the elevator thought experiment, I concluded that the effects of gravitation and those due to acceleration cannot be distinguished. Your mechanics, Sir Isaac, distinguishes between the motion of a body that is inertial (subject to no forces) and the motion of a body subject to the action of gravity. The former is rectilinear and uniform in an inertial system; the latter occurs in curvilinear paths and is non uniform. The principle of equivalence, however, does not allow this distinction.

Newton:
I do not see at the moment why this distinction is necessary.

Einstein:
I then tried to state the law of inertial motion in the generalized sense. The solution of this problem banishes both the notion of absolute space and force and gives us a theory of gravitation.

Newton:
I was never comfortable with the concept of absolute space, although I argued for it and even came up with two thought experiments, the “rotating bucket” and “the two globes in the void” thought experiments. But I was less comfortable with the notion of ‘action-at-a-distance’.

Dr. Cohen:
Sir Isaac, I remember reading a letter you wrote to Richard Bentley, in 1693 I believe. You said something like” ...that one body may act on another at a distance through vacuum, is to me an absurdity”. And then you continued by saying that “Gravity must be caused by an agent acting constantly according to certain laws; but whether this agent be material or immaterial is a question I have left to the consideration of others”.

Newton:
Yes, I remember that letter…

Einstein:
Sir Isaac, it seems to me that the enormous practical success of your theory may well have prevented you and the physicists of the eighteenths and nineteenths centuries from re-examining the basic assumption you made.

Newton:
Perhaps. Of course, I knew that Kepler’s law applied to an ideal system of one body being attracted to a central force governed by the inverse square law. I knew that the orbits of planets did not really move according to these laws. But the theory was very successful, when I applied the theory to calculate the mutual attraction of two and three bodies and began what you call perturbation theory.

Dr. Cohen:
Sir Isaac, your great triumph came when the prediction of the return of Haley’s comet was confirmed. Unfortunately, that came after you died. But I am sure you never doubted it.

Newton:
No, I did not. But of course my gravitational theory is still used today when you calculate the period of artificial satellites or take a trip to Mars,

Dr. Cohen:
Another triumph of your theory was the prediction of a new planet whose gravity affected the planet Uranus. Uranus was discovered after your time, by the British astronomer, William Herschell, Sir Isaac.

Newton:
So, was my gravitational theory questioned?

Dr. Cohen:
Indeed, it was. But then by the efforts of a staunch Newtonian, the French astronomer Leverrier calculated the position of a new planet. Astronomer looked at the predicted where to look and another astronomer promptly found a new planet. And your theory was saved.
There is a pause.
Professor Einstein, could we conclude our discussion with the observationally testable consequences or predictions, of your general theory of relativity.

Einstein:
Alright. Let me say from the start that, although the mathematical apparatus that leads to these predictions is formidable, the effects themselves are explicable in terms of relatively simple mathematics.
He stops for a moment and then continues:

In 1915, I put forward three experimental results which could be used as tests for the theory. The first was the redshift of spectral lines emerging from large objects like the sun.
He turns to Newton and briefly explains the redshift phenomenon in general

Newton:
A simple principle that can be applied to any wave motion. Very ingenious!

Einstein:
Actually, I predicted this effect as early as 1907. That means that we do not have to use general relativity to calculate it.
He goes to the black board and explains, especially the difference between redshift produced by the Doppler Effect and the redshift produced by gravity. You simply take E = hn (Planck) and $E = mc^2$ *(Einstein) and apply Newtonian gravity.*

Newton:
But I am curious to know, Professor Einstein, being aware of this simple derivation, why you did not use it during or after the completion of the general theory.

Einstein:
Well, when I was working seriously on the general theory, between about 1910 and 1915, the photon concept was accepted by only a few, hard as it is to believe. Even Max Planck, who was the originator of the theory in 1900, and was the first to write E = hν, could not accept it as I presented the photon in my 1905 paper!
He pauses

You see, although Planck postulated the quantization of electromagnetic radiation in a black body, he did not think that radiation itself was quantized!

Dr. Cohen:
I see. So you wanted to avoid having your theory tainted, as it were, with an idea that was still thought to be speculative?

Einstein:
Quite so. But I soon realized that a reduction in the photon's frequency would also be equivalent to an increase in its time period, or, using the photon as a standard clock, a dilation of time. A time dilation automatically implies a length contraction by the same factor.

Dr. Cohen:
The next effect is the most famous, namely the gravitational deflection of light. Most people think that this is an effect that occurs only in the general relativity theory. But that is not so. One can calculate the deflection of a particle of mass m, moving with a velocity of light c.
He stops and then continues:

Henry Cavendish calculated this deflection, and so did Laplace. Later the Bavarian astronomer Johann von Soldner in 1801 also provided a solution. He assumed a standard Newtonian orbit for a 'particle' of light of mass m, passing by the edge of the sun.

Newton:
I am pleased to hear that my theory was used to predict the bending of light!

Newton:
What would the newspaper have reported then?

Einstein:
I admit, that was lucky.
The final effect that I described was the precession of Mercury's orbit. This was my "jewel in the crown" in experiments involving general relativity. But we do not have time to discuss this now.

Dr. Cohen:
Just one question, Professor Einstein. We now know that it is possible to calculate the exact precession of 43 seconds of arc, using only Newton's gravitational theory and combined with your special theory of relativity. Did you ever try solving the precession problem applying special relativity to Newtonian gravitational theory?

Einstein:
Actually, the idea occurred to me, but rather than labour over that approach, I thought that the general theory of relativity, once complete, should reduce to Newton's theory and the special relativity for small values of the gravitational field.
He stops for a moment and then says:

I was beside myself for a whole week and could not work.

Newton:
Gentlemen, it sounds like my theory did go a long way and was found inadequate only in some very exotic details. Then why did it take another seven years to construct the general theory of gravity?

Einstein:
The reason, Sir Isaac, is that it is not easy to free oneself from the idea that coordinates must have an immediate metrical meaning. In other words I was firmly convinced that space in is not merely the stage on which material objects move and interact. I believed that the fundamental geometry of space depends on the presence and distribution of matter. I can best express this idea this way: 'Gravity is due to a change in the curvature of space-time, produced by the presence of matter'.

Dr. Cohen:
In my student days, I have heard the cosmologist John Wheeler sum it up this way: "Matter tells space how to curve; space tells matter how to move".

Einstein:
That is even better said.

Dr. Cohen:
So you were forced to go from Euclidean to non-Euclidean geometry to describe this relationship between matter and space?

Einstein:
Yes. And that was difficult for me. I had to become acquainted with the non-Euclidean geometry that was originally developed by Lobotschevski and Bolyai and later by Riemann. Even though my friend, the mathematician Marcel Grossmann, assisted me, it was still a great struggle.

Newton:
I, too, had to struggle, when I wrote the *Principia* as far as the mathematics and my geometric reasoning is concerned.

Einstein:
But you, Sir Isaac, had to invent almost all your mathematics yourself. But for me one thing is certain: never before or after in my life have I troubled myself over anything so much. Compared with this problem, the original theory of relativity is child's play.
There is a pause and Dr. Cohen looks at Einstein.
And then he looks at Newton.

Dr. Cohen:
I believe we have almost come to a closure. Professor Einstein must have his rest.
Newton and Einstein both nod.
This was an extraordinary experience for me to meet you both. Thank you very much.
Both nod and smile.

Newton:
Yes. Extraordinary.

Dr. Cohen:
I believe that there will be a time when your efforts to find a unified field theory are thought to be a waste of effort, but I think that theoretical physicists will again be concentrating with relating Einstein's general theory of relativity to quantum mechanics into a quantum theory of gravity. This then would be a first step toward what we might call a "Theory of Everything". But quantum mechanics and general relativity are still considered inconsistent.

Einstein:
I hope you are right, my friend.
I think quantum mechanics is today where classical mechanics was before relativity. They are both very successful but incomplete. The GTR was different only in small deviation from Newton's theory. Similarly, I believe, when a new theory emerges, present quantum mechanics may survive, perhaps with only minor adjustments.

Dr. Cohen:
So you are saying that quantum mechanics represents a major advance, and yet it is only a limiting case of theory which remains to be discovered.

Einstein:
Quantum mechanics is very impressive. But an inner voice tells me that it is not yet the real thing. The theory yields a lot, but it hardly brings us any closer to the secret of the Old One. In any case I am convinced that He does not play dice.
He stops for a moment and then adds:

Newton:
Professor Einstein, how would you describe this future theory? I am interested, because I, too, gave a description of a future theory.

Einstein:
What I have been trying to do may seem a bit crazy.
He stops and smiles.

This theory should have the following constraints: It shall be strictly causal, it would unify gravitation and electromagnetism, that all the particles of physics shall emerge as a special solution, and finally, that the quantum postulates shall be a consequence of the general field equations.
Einstein stops and smiles.

I know it sounds very ambitious. But I am convinced that the statistical nature of quantum theory is superficial. It must be backed by the principle of general relativity.

Newton:
That would really be a theory of everything! I, too, proposed a future program in the *Principia.*
I wrote:

“The essential task of natural philosophy is to demonstrate quantitatively how particles of matter, in motion and endowed with the forces experience shows them to possess, produce the observed phenomena of nature”.
And I continued this way:
“I wish we could derive the rest of the phenomena of nature by the same kind of reasoning from mechanical principles; for I am induced by many reasons to suspect that they may all depend upon certain forces by which the particles of bodies, by some causes hitherto unknown, are either mutually impelled towards each other, and cohere in regular figures, or are repelled and recede from each other; which forces being unknown, philosophers have hitherto attempted the search of nature in vain; but I hope the principles here laid down will afford some light either to this or some truer method of philosophy”.

Einstein:
I think your program has been, at least in part, been achieved.

But let me close with a less optimistic remark .I do not think there is a single concept of physics of which I am convinced that it will stand up. I have been working on the UFT for about thirty years, but I am unsure if I am even on the right road.

My contemporaries, however, see me as a heretic and a reactionary who has, as it were, outlived himself.

The two guests are moving to take their leave. Einstein gets up, goes to the table and picks up the balloon. He holds it high.

Einstein:
Why don’t we go outside and test the principle of equivalence? We can ask my neighbor, the young physicist Eric Roger to take us for a ride in his big Ford. He is a very friendly fellow. He is the one who made and gave me the toy last week. I think this might amuse him, too.
Russell looks at Sir Isaac. Sir Isaac smiles and nods.

Newton:
Well, this will be a new experience for me. Both being in a mechanical carriage and experiencing the demonstration.

Newton:
Well, this….demonstration—but please do not drive too fast! Remember, according to my gravitational theory if we reach a speed of about 8 miles per second we would leave this wonderful planet!

Einstein:
He laughs heartily.
Don’t worry, Sir Isaac, in America we have a speed limit of 65 miles an hour
But I have heard that in Germany there is no speed limit on highways.

They all laugh and slowly move off the stage.

Newton:
Well, this will be a new experience for me. Both, being in a mechanical carriage and experiencing the demonstration of the equivalence principle.
He pauses, then exclaims:
What an agreeable way to end our discussion. Let us go.
Einstein hands the balloon to Newton, and Newton holds it high. They three leave, loudly chatting and laughing....
Einstein is seen waving. They disappear.

Pause, applause,

The commentator comes back comes back and presents concluding remarks.
Invites audience to ask questions. The three come back and answer these questions.

(Perhaps we can have one or two members of the audience prepare questions?)