MARKUS KLUTE: Welcome again to 8.701. So this is the fifth section of our introduction. I'd like to talk about the early history and the people involved in nuclear and particle physics. I cover the period from 1820 to the beginning of the Second World War. other elements of the later history of the development of the standard model-- parity violation, CP violation-- those aspects will be covered when we talk about the actual physics involved.

But I'd like to give you some more background. Especially since we start the discussion with particle physics, it's good to understand what was the starting ground, which shoulders did people stand on at the time.

Important to realize here, at this point, I'm not an historian. I like to read about history. I just finished an interesting book on Einstein. I like to have a good understanding how the people of the time, the time itself, and the physics discovery interacted. It helps me in understanding the process of being scientific.

When you look at history, you find a lot of places where progress was made by curiosity and by doing things which are not the common way to proceed. And so one learns this by looking at history. And I might give you a number of examples here as well.

So diving in one of the questions at the time, going back, again, almost 200 years is how old was the Earth? How old is the Earth? And about 200 years ago, people started to argue whether or not the 10,000 of years, which was long thought to be the age of the Earth, are actually correct.

And specifically geologists and biologists argued that this cannot be true. They observed how slowly geological and biological processes such as erosion and evolution occur. And if you just try to, by observation, put all of those ducks in a row, if you want, you find that the Earth must be much, much older than those 10,000 years. On the contrary, some physicists argued that the Earth cannot be as old as several hundreds of millions of years because it would be, by now, a very cold and dark place.

One of the opposers of evolution was Lord Kelvin, or William Thompson. And he argued with classical thermodynamics calculations that the Earth cannot be as old as those 300 million years as Darwin writes in initial printing of *The Origin of Species.*

Herman Helmholtz, a few years later, tried to use energy compensation principles to calculate how much heat from the sun would radiate if the energy comes from slow contraction. And he, by converting gravitational potential energy to heat, calculated age cannot be more than 18 million years.

So putting those together, you find, on the one side, the physicists, theology might be a different dimension to this discussion, and then geologists and biologists. And a complicated question. I mean, really there was something to be learned. Something was not quite understood. And so we come back to this question. Next slide. But then progress was made in the understanding of physics. And here to be named are Henri Becquerel, for example, for the discovery of radiation from uranium and Ernest Rutherford for the discovery, by studying this radiation, that there must be at least two different sources of radiation. And he called them, simply by following the Greek alphabet, alpha and beta rays.

In the same year, J. J. Thompson discovered a particle, the electron charged particle, or the electron. Becquerel's story is quite interesting, as he was trying to understand the material Roentgen studied. And he was interested in figuring out what fluorescence material can do. And again, this is one of the examples where he, by accident, discovered that it is actually not the fact that you have a material, you expose this to sunlight, you wait a little while, and it still radiates the light. So this has delayed the fluorescence of the material. It is not quite the full story to some fluorescent materials.

So he discovered this by accident, by putting the mineral in a drawer, together with a photo plate, and found that there was only a very short, limited evidence from that photo plate to be radiated by the sun. But it was basically foggy from being in the same drawer as a mineral. But this was a rather accidental discovery.

Marie and Pierre Curie proposed the new term, radioactivity, for materials which generally emit light. And they discovered additional materials to the uranium which was discovered by Becquerel. So they discovered thorium, for example, and later also the elements of polonium and radium. And they discovered that those elements radiate a lot of radioactivity.

So Marie Curie was able to measure the energy being radiated, and found that a gram of radium can emit up to 140 calories per hour. And so you find that a gram of radium is able to power, basically, the energy you need in order to survive-- provide the energy.

So moving a little forward, so then uranium specifically, but other radioactive materials, were studied. And Paul Villard discovered that there must be a third component of radiation which behaves different from the other two. And he called these gamma rays, again, simply following the alphabet and moving along to the third letter.

Rutherford then connects these findings first to the question of the age of the Earth. And he simply suggests that it's those radioactive elements which are in ores in the core of the Earth which provide additional source of feed sufficient, because of the connectivity of the Earth, to keep the Earth geologically active. And he comes to the conclusion that the Earth might be as well a few billion years old, as we know now it is.

So putting this in context, at the very same time in Bern, Switzerland, a clerk named Albert Einstein has a fantastic year. He, in one year, comes up with a sequence of theoretical discoveries. One is special relativity. And he uses the findings of special relativity to derive that there's an equivalence between energy and mass. And this equivalence, as we will see later, when we discussed nuclear physics specifically, is very important to understand nuclear decay, nuclear fission, and nuclear fusion, and figuring out why, if you have a component state that seems to be lighter than the sum of the individual components making up this particle.

Rutherford was a pioneer with collider experiments in the sense that he used other particles a lot to bombard all kinds of materials. So what he found first is that, if alpha particles, when stopped, turn into helium. So the alpha particle itself grabs on to the electrons from the material it collides in. There was a technical problem. I'll just continue. And that turns into helium.

His students, Marsden and Geiger, then perform a very famous gold foil experiment. So you all probably have heard about this, taking an alpha particle source and you shine it on a foil of gold. And then you look at the angular distribution of the particles, which go through or which have been backscattered from this foil.

And Rutherford then takes those measurements and turns them into a solar-system-like model of atoms which are essentially made out of empty space and a very small, intense nuclei. So Rutherford then continues with this experiment and it's able to produce, by bombarding nitrogen with other particles, protons and oxygen. And this is, in fact, the first human-engineered nuclear reaction. So now we are in the year 1919, just after the First World War ended.

On the theoretical side, this is the time that quantum mechanics is developed. And Dirac then combines relativity with quantum mechanics, which then leads to the so-called Dirac equation, which we're going to look at very shortly in this class as well.

This equation is quite interesting because it predicts the existence of negative energy states. And so then that just comes out of the equations. And then you ask yourself, what's happening here? You can have an interpretation that, for an electron, of the electron which traveled backwards in time, or you interpret them as electrons with negative energies. And so this then leads to the prediction of antimatter.

Pauli and Fermi, they're puzzled by a problem of energy conservation in the second case. And so this is something which is rather weird and is a big challenge to the physics of the time. And they've solved this challenge by proposing a new particle which is rather light and doesn't interact with the detectors they had available at the time. So it just escapes undetected. They call this particle the neutrino.

A year later, neutrons are directly detected in experiments by Chadwick with beryllium and other particles again. And then the predicted anti-electrons, the positrons, were discovered by Anderson in tracts of photographic plates which looked like electrons but they curve in the wrong direction. So either they have the opposite charge or they travel backwards in time. They didn't have quite the time resolution to [INAUDIBLE].

All right, also on the theoretical side, it needed to be understood how neutrons and protons actually bind together in nuclei. And so Hideki Yukawa proposes the existence of a strong force which is really, really strong and binds those nuclear together to a degree that you cannot easily break them apart.

And then Bethe calculates how nuclear fusion, rather than the fission process, can be used in order to power the sun. So for this, he proposes a three-step process, the so-called proton-proton chain, which I will not discuss here but we will certainly discuss later in this class.

And then there's more developments in the area of nuclear physics. And this progress is made by, again, using all kinds of materials and bombarding with each other. So for example, by colliding neutrons with uranium, one discovers a process of nuclear fission. This was done by Lise Meitner and Otto Hahn in the late 1930s.

So from there on, there's interesting further developments going on in the sense that many physicists at the time in Europe are rather concerned by the developments of the Nazi Party in Germany. In the '40s already after the start of the Second World War, Albert Einstein wrote a letter to Theodore Roosevelt pointing out that there is a real threat that the Nazis are going to develop a bomb based on nuclear processes.

And so this then led to the Manhattan Program in the US and the development of the first nuclear bombs or atom bombs. And in August 1945, the first two bombs were dropped on Japan, which led then to the surrender of the Japanese empire and the end of the Second World War.

With that, I stop the discussion of those early developments. I hope you got a first glimpse and use this as a starting point to read further. Those characters, Lise Meitner, for example-- I'm looking at her picture right now-- very, very interesting to see how those people were connected, how those people communicated, and in which environment they had to work. Lise Meitner, for example, was Jewish. And she left Europe, had to flee from the Nazis in the '30s, while making these kind of discoveries.

Also interesting is maybe the historical introduction to elementary particles. I have this here in David Griffiths' book. This starts with this kind of classical era and then goes beyond the Second World War and introduces the findings in particle physics beyond what I explained to this point. So I hope you enjoyed this. This is basically the last of these introductory lectures which doesn't come with a set of problems, with a set of things you should be interacting with. So the next one will already do that. And we will use this in the Thursday recitation of the first week to have discussion.