The History of the Twentieth Century
Episode 9
“Dark Clouds”
Transcript
(Provided by listener Joseph M.)

[music: Fanfare]

In 1900, Lord Kelvin, the preeminent scientist of the time, was 76 years old. He was kind of the Neil deGrasse Tyson of his day. He gave science lectures, and was the go-to guy for journalists who wanted to write pieces about science. He gave a lecture that year entitled “Nineteenth Century Clouds over the Dynamical Theory of Heat and Light,” in which he identified two “dark clouds,” as he called them, over modern science, that were spoiling what was otherwise an elegant and virtually complete picture of the world around us. Solving these two mysteries, he suggested, would pretty much complete our understanding of the world around us. Lord Kelvin’s two dark clouds, and others he hadn’t even suspected, would upon investigation turn out not to complete science’s understanding of the physical world, but would instead open up a Pandora’s Box of new scientific puzzles, some of which we are still working though to this very day.

Welcome to *The History of the Twentieth Century.*

[music: Opening Theme]

Episode 9. Dark Clouds.

In the realms of physics and chemistry, the great accomplishments of the 19th century did indeed revolve around heat and light. The 19th century saw the rise of the steam engine which converts heat into useful work, which led physicists like Lord Kelvin to investigate the physics of heat. Lord Kelvin, while still in his 20s became one of the first physicists to understand that what we call heat was the vibration of molecules in an object. One of the consequences of this understanding is that there is such a thing as the coldest possible temperature. The temperature when molecular motion stops altogether. Today we call this temperature absolute zero. And we measure temperatures relative to absolute zero in degrees Kelvin[1], which are named after Lord Kelvin.

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[1] Kelvin is not referred to as a degree, unlike Fahrenheit or Celsius. Though anyone will understand your meaning if you do refer to it as such [footnote from Joseph M.]

It is so often the case in science that scientists do their best work when they are young and tend to become fuddy-duddies when they're older and respected, and to some extent this was true with Lord Kelvin. Late in his life he commanded great respect and issued pronouncements on many scientific questions. Inevitably he was wrong about some of them. He flat out refused to believe in x-rays when Röntgen first reported them—I'll get back to that—and denied the possibility of heavier than air travel, even after the Wright Brothers did their thing at Kitty Hawk in 1903. It may well have been Lord Kelvin whom Arthur C. Clarke had in mind when he formulated Clarke's First Law: "When a distinguished but elderly scientist states that something is possible, he is almost certainly right, when he states that something is impossible, he is very probably wrong."

Besides thermodynamics, the 19th century saw tremendous advances in the understanding of electricity and magnetism, most importantly that there is such a thing as electromagnetic radiation and that one expression of that is what we call light. The team of the experimental scientist Michael Faraday and the theoretician James Clerk Maxwell had developed a set of equations that completely described the behavior of electricity and magnetism and electromagnetic radiation, including light. The thing I always think is coolest about Maxwell's equations is that you can use them to derive the speed of light from the measurable properties of electricity and magnetism. And it turns out that yes, electricity and magnetism and light are also bound up with waves and vibrations and heat and energy.

So the end of the 19th century brings us to a point where pretty much all observable phenomena in the world around us can be explained by a few elegant equations. And that's what Lord Kelvin was talking about in his lecture, except that he had identified two dark clouds: experimental results that couldn't yet be explained by these beautiful equations.

One was the Michelson-Morley experiment, which relates to measuring the speed of light. I'll have to ask you to forgive me, but I'm going to have to punt on the Michelson-Morley experiment for now. We'll come back to that in a future episode. The other was the black body problem—that one's easier to explain.

I'm sure you know what happens when an object, say the coils on an electric range, are heated. At first they look no different, but if you hold up your hand to them you can feel heat radiating from them. As the temperature goes up the coils begin to glow a dull red, then a brighter red, then orange. Hopefully this is as far as your range-top has ever gotten, but if the temperature continued to rise, the object would glow yellow, and then white, and finally maybe even have a touch of blue. All objects do this, and the relationship between the temperature of the object and the color it radiates is independent of what material it is you're heating. But here's the dark cloud: why? Oh, 19th century scientists understand perfectly well how heat generates light, that's not the issue. The issue is, why these particular colors and these particular temperatures? What process controls the colors? It may seem like a silly little question but great things are going to come from it.

And here are a couple of other unsolved questions from the 19th century that Lord Kelvin has been pondering. What makes the sun hot? By 1901, science understands that the sun is a big ball of gas. But where does all the heat and light come from? The only mechanism scientists like Lord Kelvin could propose was compression. That is, the Sun is slowly shrinking, and the pressure of the gas builds up, and that generates heat. A rate of shrinkage one mile every four years would be enough to account for the heat and light the Sun puts out, as the science of the time calculated it. But the Sun is less than a million miles in diameter; that suggests it can't keep this up much longer. Now there's a scary thought.

On the other hand, what does it suggest about the age of the Sun? Suppose we project backward. We envision a sun that was much bigger and less dense in the past. In fact, about 20 million years ago under this model it was as big as the Earth's orbit. And what does that tell us about the age of the Earth?

Lord Kelvin knew, as we know, that the interior of the Earth is very hot. The planet has a molten core, and it's only the top couple of miles where the planet is cool enough not to burn us all up. Thermodynamics is Lord Kelvin's specialty, remember. He set to work trying to calculate how long it would take for a molten planet to cool off enough to resemble the earth as we know it today. Again, he got a figure of about 20 million years. Victory! It looks like we now have a handle on the age of the Earth, as well as a clue to the formation of the solar system.

The Sun is a gradually shrinking cloud of spinning gas that occasionally throws off fragments of material. These become planets. Implicit in this idea is that the farther out a planet is, the older it is, and planets closer to the sun are newer. Mars, for instance, must be a lot older than the Earth, and Venus must be a lot younger. That's the reason why, in his 1897 science fiction novel *War of the Worlds*, H.G. Wells assumed Mars was an older planet with an older civilization. This idea would persist in science fiction for some time. When C.S. Lewis wrote *Out of the Silent Planet* in 1938 and *Perelandra* in 1943, he envisioned a Mars much older than Earth and Venus much younger. Heck, Venus with its thick, cloudy atmosphere that astronomers can't see through is probably a hot and steamy jungle with dinosaurs roaming around through it, as other science fiction authors would imagine.

The problem with this picture is the biologists, who were all wound up over one of *their* big revelations of the 19th century, Darwin's theory of evolution by natural selection, don't buy the 20-million-year age of the Earth, because that is not nearly enough time to account for the wide diversity of species that live on the planet today. The biologists figure that the Earth must be a lot older. Perhaps 500 million years, or even more. It's a problem, and it will take until the midtwentieth century before the astronomers and the geologists and the biologists all land on the same page on the question of the age of the Earth.

Now I bring all this up, not to make fun of science in general, or Lord Kelvin in particular, who's just a reasonable guy trying his best to speculate on big questions. What I am trying to do is give you a sense of what people knew and didn't know at the dawn of the twentieth century.

[music: Holst, *First Suite in E♭ for Military Band*]

At the time Lord Kelvin gave his lecture in 1900 there were other dark clouds hanging over the dynamical theory of heat and light that he himself perhaps did not fully appreciate. There was for instance the recent discovery of Wilhelm Röntgen, a German physicist. Late 19th-century physics was interested in cathode ray tubes[2]. These are glass tubes with two metal plates inside from which most or all of the air has been removed, or maybe replaced with some other gas. When you apply a voltage across the plates, something moves between them carrying an electric current. But what is it exactly? The science of the time called these cathode rays. Depending on what kind of gas was in the tube you might see a colorful glow; this is the principle behind our fluorescent lights and neon lights. The eerie glow from these cathode ray tubes was a frequent public scientific demonstration in the late 19th century. It made audiences go ooh and aah. But this unique interaction of electricity and light was just the sort of thing that 19th-century physics was supposed to be all about, and yet these cathode rays were still not well understood. And so, physicists were experimenting with them, including Wilhelm Röntgen.

What Röntgen discovered was that when he switched on his cathode ray tube, a nearby sheet of phosphorescent material started to glow. This phosphorescent material is that glow in the dark stuff we all know about. You expose it to light, and then later when it's in the dark, it glows, at least for a little while. It seemed some kind of invisible radiation was coming out of the cathode ray tube and energizing the phosphorescent material the same way light does. Röntgen dubbed these "x-rays," using "x" in the mathematical sense of an unknown. He probably intended it as a temporary name. But it stuck, at least in the English-speaking world.

Röntgen set up his screen of phosphorescent materials and fired x-rays at it, and then held up objects in between to see what kind of shadows they might cast. When he held up a piece of metal it cast a nice sharp shadow, proving that x-rays move in straight lines like light does. But, as you've probably already guessed, what was more interesting was the shadow that Roentgen's hand cast on that phosphorescent screen. X-rays passed through his hand at different intensities depending on what was inside. Meaning that he could see an image of the bones inside his own hand projected right there on the screen.

[2] People of a certain age may remember these as television screens and computer monitors [footnote by Joseph M.]

Röntgen was so astonished by this discovery he kept it to himself for a while, as he experimented further with his x-rays, to make absolutely sure he was seeing what he thought he was seeing. Afraid he would become a scientific laughing stock if it turned out he was making some kind of mistake. That didn't stop him though from inviting Mrs. Röntgen to come out to the lab and hold her hand up in front of the screen. It scared the crap out of her. In my house you pull a stunt like that and you're going to be sleeping on the sofa for a few days.

Röntgen published his discovery in 1895. Lord Kelvin was convinced that Röntgen was a fraud at first, but came around when he saw his own hand x-rayed. Röntgen would win the very first Nobel Prize in Physics in 1901 for the discovery of x-rays and would become one of those German scientists I was bragging about in Episode 2.

Naturally, Röntgen's discovery inspired many other physicists to start playing around with cathode ray tubes and experimenting with x-rays. Röntgen himself discovered early on that lead seemed to block x-rays entirely and so he was careful to use lead shielding in his own experiments. But other experimenters weren't so careful. And by 1900, several of them were reporting symptoms like skin burns on places that had never been exposed to heat and sudden hair loss.

One of the scientists who got interested in Röntgen's work was the French physicist Henri Becquerel. Becquerel was interested not so much in the x-rays themselves, but in the phosphorescent material. He wondered if these glow-in-the-dark phosphorescent materials might not be giving off x-rays as well as visible light. Well he was completely wrong about that. But in the course of experimenting with phosphorescent materials he left some in a drawer with a photographic plate. When he developed the plate it showed traces of radiation from the phosphorescent material even though the phosphorescent material hadn't been exposed to anything and wasn't glowing. Weird, huh?

When Becquerel experimented further he realized that this trick only worked with phosphorescent materials that contained uranium. Uranium ores occur naturally in certain minerals, notably pitchblende, and people have been using uranium ores as a coloring agent for glasses and ceramics since ancient times. The discovery of uranium as a chemical element, however, didn't come about until 1789. The planet Uranus had been discovered just eight years earlier, and that was a pretty big deal, being the first time anyone, anywhere had ever discovered a whole new planet, and so the new element was named uranium in honor of the new planet. And that was as much thought as anyone had given to uranium, which appeared to have no practical use, until 1896 when Becquerel came along and announced that uranium gave off some kind of radiation, something like x-rays, that could penetrate materials like paper that were opaque to light. And unlike x-rays, which were clearly being powered by the electricity applied to the cathode ray tube, this radiation was emitted spontaneously by a lump of metal with no visible power source. Where the heck was all this energy coming from?

So now we have three mysteries going, the mysterious radiation coming out of uranium with no power source, x-rays, and cathode rays. You didn't forget about the cathode rays, did you? You know, the thing that started all of this? Well if you remembered the cathode rays congratulate yourself. You're in the same league as the English physicist Sir Joseph John Thomson. Who everyone seems to call J.J.

J.J. Thomson was a physics professor at the University of Cambridge who went to work methodically experimenting with cathode rays, those mysterious rays that moved electricity from one metal plate to another, through vacuum in a glass tube. Physicists of the time debated whether these things were something massless and immaterial, like light, or whether they were actually tiny particles of something carrying electric charge from one plate to the other. By trial and error Thomson showed that cathode rays could be deflected by a magnetic field. This implied that cathode rays were small particles of…something, and not a massless wave like light or x-rays, which can't be deflected by magnetism. He then went on to show that cathode rays could also be deflected by an electric field, and by measuring the deflection he was able to calculate the mass of the particles. Or at least the charge/mass ratio, which is good enough. Don't ask me to go into it any deeper because then I'd have to break out the math.

His calculations showed that the tiny particles that made of cathode rays only had about 1/1000 the mass of a hydrogen atom, the smallest known atom[3]. Thomson wanted to call these particles corpuscles. But other scientists preferred the term "electron" a portmanteau of *electric ion,* and that was the name that stuck.

Now this was pretty amazing. As I mentioned back in episode 1, the idea that all materials in the universe are made up of collections of atoms is generally accepted by the beginning of the twentieth century, but nobody has actually come up with experimental proof that these atoms are a real thing. They are still just a theoretical concept. But when scientists talked about atoms, they were envisioning something fundamental and indivisible. The very word "atom" comes from Greek and means "indivisible." Some theoreticians suggested that atoms were not physical objects at all, but vortices in the ether. And if that doesn't make any sense to you, I'm sorry but I'm going to have to punt on that one too.

But now here's J. J. Thomson in 1897, before the existence of atoms has even been confirmed experimentally, demonstrating the existence of something that's very much smaller than an atom. And not just smaller than an atom. Thomson realized early on that these corpuscles—I mean electrons—are likely one of the building blocks that make up an atom. This was an extraordinary

[3] Although hydrogen is the lightest atom, its atomic radius is larger than helium. [footnote by Joseph M.]

claim. Here atoms are supposed to be the smallest thing that any physical object can be divided up into, but now the atom has been dethroned as the fundamental particle of the universe before it has been even proved to exist.

[music: Holst, *First Suite in E♭ for Military Band*]

And that brings us to Marie Curie. Maria Skłodowska was an ethnic Pole, born in Warsaw, in what was then the Russian Empire, in 1867. She came from a family of teachers and scientists who were struggling because they were also Polish nationalists. 14-year-old Maria reportedly got up and danced when she heard the news that the Russian Emperor and titular King of Poland, Alexander II, was assassinated in 1881.

In those days the Russian government was trying to stamp out the Polish language and culture. Schools were only permitted to teach in the Russian language, and their curricula were closely supervised by the government. Poles responded to this by creating clandestine schools where Polish students could study in their own language. The Russian government itself in a report in 1901 estimated that a third of Polish students were studying in these underground schools. One such school was the so-called Floating University of Warsaw, where Maria got her college education. Because, aside from issues of culture and government suppression, the Floating University accepted women students, which many of the above-board universities did not.

In 1891, Maria followed her older sister to Paris, and enrolled in the University of Paris where she earned master's degrees in physics and math. In 1894, she won a contract to do research on the magnetic properties of steel. She needed laboratory space, and was referred to one Pierre Curie, eight years her senior. His lab space wasn't suitable, as it turned out, but something else about him must have been, because they fell in love, so there's that.

Marie had planned to return to Warsaw after completing her education in Paris and so she didn't see a future with Pierre and rebuffed him, until Pierre promised to move to Warsaw with her. But she was unable to get a teaching position back in the Russian Empire, because she was a woman. So she returned to Paris to get her doctorate, they were married, and became partners in both love and science.

This was just about the time that Henri Becquerel had announced his discovery concerning uranium. As a doctoral student, Marie picked up on his discovery at a time when other scientists were still more interested in Röntgen's x-rays. It was Marie Skłodowska Curie, which is what she liked to be called, who in 1898 first coined a term for Becquerel's discovery: *radioactivity.*

Pierre Curie and his brother had earlier invented a more sensitive form of electrometer, which is a device for measuring the presence of an electrical charge. Marie discovered that electrometers could be used to detect radioactivity. And so she became the first researcher to study radioactivity in a quantitative way. Her first discovery was that the radioactivity of uranium was constant. It didn't matter if the uranium was a solid block, or ground into a powder, or dry, or wet, or exposed to light, or kept in darkness. It didn't matter whether it was elemental uranium, or a uranium compound. This is an important discovery because it suggests that radioactivity is not a chemical process. You know chemical reactions can do all sorts of things: emit heat or light, generate smoke or gas, change color, produce electricity, so it wasn't crazy to think that radioactivity was some sort of chemical reaction. But it wasn't. Marie's results implied that radioactivity was something that came out of the uranium atom itself. This was revolutionary, because like J.J. Thomson's research, it implied that atoms themselves could be broken down into something smaller.

Marie solicited samples of every other chemical element known at the time in 1898. She hit the jackpot with thorium, which also turned out to be radioactive. She published this finding, only to discover that she had been beaten to the punch by just a few weeks by a German scientist named Gerhard Schmidt. She learned her lesson, and in the future she published every finding as quickly as she possibly could, and no one ever scooped her again.

In working with uranium ores, Marie made another startling discovery. Uranium ore is more radioactive than the uranium you extract from it. Marie and Pierre set to work on pitchblende, a mineral containing uranium ore, laboriously separating it out using various chemical techniques. This is a complicated project because a mineral like pitchblende can contain dozens of chemical elements. They were able to separate out two different radioactive sources from the ore besides the uranium, which they declared to be two newly discovered radioactive elements.

They named the first one polonium, in honor of Poland, or Polonia in Latin. Remember now that Poland has not existed as an independent country for a hundred years, so this was unquestionably a political statement, and a pretty radical one for the time. The second element they named radium, because it gave off radiation.

The Curies then set to work trying to isolate samples of pure polonium and radium. They never were able to isolate polonium. Today we know that's because polonium has a very short half-life, about 137 days. Which meant that the stuff was disappearing about as fast as the Curies could isolate it. They had better luck with radium, though it took years and a ton of pitchblende, and yes I mean a literal ton of pitchblende, to produce a fraction of a gram of radium by 1902.

In 1903 the Curies were invited to speak to the Royal Institution in London, except that they wouldn't let a woman speak, so Pierre had to give the lecture on behalf of the both of them. Although Lord Kelvin expressed his opinion on all of that by inviting Marie to come sit next to him. Later that year Marie would get her doctorate, the first woman ever to be awarded a doctorate in France, and the two of them, along with Henri Becquerel, were awarded the 1903 Nobel Prize for Physics. Originally the prize was to just go to Becquerel and Pierre, but when Pierre got wind of this he wrote a letter declaring that a Nobel Prize for research into radioactivity was meaningless, unless it included Marie. They gave in and included her, and she became the first woman to win a Nobel Prize[4].

The Curies became international celebrities, they spent their Nobel Prize money to upgrade their lab and hire an assistant. Sadly, Pierre was run over in the street by a horse-drawn wagon in 1906 and killed. Marie continued her research alone. The French government offered her a pension to help her support her children, but she turned it down. She was invited to take up Pierre’s position at the University of Paris, and thus became the first woman professor in the 700-year history of the university.

In 1907 she received a grant from America, and used it as seed money to create the Radium Institute, which today is called the Curie institute, to continue her research into radioactivity, and also to begin investigation into the medical applications of radioactivity. The Curies’ research had already shown that radium radiation could shrink cancer tumors, so that looked promising.

In 1910 a vacancy opened up for a physicist in the French Academy of Sciences. Marie applied for the seat. Her main competition was Édouard Branly, a physicist at the Catholic Institute of Paris, who had developed new inventions in the field of telegraphy. And this is where Marie ran afoul of French politics. You may recall from last week’s episode, the bitter divisions between republican liberals and Catholic conservatives in France during the Dreyfus Affair, which was unfolding at the same time the Curies were beginning their research, Branly was a native born Frenchman with impeccable Catholic credentials, while Marie was a woman, an atheist, a foreigner, and had well known liberal connections. The right-wing press, who were happy to call her a French scientist when she was out winning Nobel Prizes, attacked her as a foreigner, and a Jew who had no business being in the *French* Academy of Sciences. Marie wasn’t Jewish, she was Polish, not that it matters, but Branly won election to the seat over Marie Curie by a two-vote margin.

Shortly thereafter, the press revealed that the widow Curie was carrying on an affair with a married colleague. The right wing press went at her again, holding up the wronged wife as a paragon of traditional Catholic French virtue and condemning Marie as an immoral Jewish foreigner. But that didn’t stop her from getting a second Nobel Prize, in chemistry this time, in

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[4] The first of only two women to receive the Nobel Prize in Physics in the whole of the 20th century. [Footnote by Joseph M.]

1911 for the discovery of radium and polonium. That made Marie Skłodowska Curie the first person ever to win two Nobel Prizes[5].

The Curies never took out any patents on their discoveries because they didn't want to impede research into the field of radioactivity. Similarly, Wilhelm Röntgen never patented x-rays. But Marie Curie's superstar status put radium on the map. The first practical use of radium was to mix small quantities of it with phosphorescent materials to make true glow-in-the-dark paint, which could glow in the dark for decades. This was used to paint markings on watch dials making it possible for you to check the time, even in the middle of the night. And this is probably why in the popular imagination we still associate radioactivity with an eerie blue or green glow, even though radioactivity is of course invisible and undetectable by human senses. Which is the reason why it's so dangerous. It would be much, much easier to avoid it if we could see it.

Also in the early years of the 20th century, medical quacks were peddling any number of radium based patent medicines, including radium drugs, radium baths, even radium toothpaste. Despite Marie's warnings to the public that radium was not well understood and potentially dangerous. Marie herself would die in 1934 at the age of 66 from aplastic anemia, probably brought on by exposure to radiation.

[music: Holst, *First Suite in E♭ for Military Band*]

I can't help but take note of how smug and self-satisfied 19th-century physics had gotten by the end of that century. But by the beginning of the twentieth century it was already clear that the proud and gleaming ocean liner of modern physics was on a collision course with the iceberg of quantum mechanics and relativity. Just as the coming Great War would give lie to the proud boasts of progress and enlightenment, or the appalling crimes of colonialism would stain the reputations of the self-appointed bearers of Christianity and civilization. It demonstrates that science is bound up in culture, no less so than art, or politics, or war. And that's the reason why here at *The History of the Twentieth Century* we try to keep an eye on all those things.

We'll have to stop there for today. If you like *The History of the Twentieth Century* follow us on Facebook at The History of the Twentieth Century or on twitter @history20th and never miss an announcement of a new episode. Or you could subscribe to *The History of the Twentieth Century* at the iTunes store. And while you're there, why not give us a rating and review. That will help other people find the podcast. And I hope you'll join me next week on *The History of the Twentieth Century* as we take a look at Great Britain. Not only is Britain the richest and most

[5] A rare achievement. Only four people have won multiple Nobel Prizes, only two in different fields. The only other person to match Curie in this feat was Linus Pauling in Chemistry and Peace. [Footnote by Joseph M.]

powerful country in the world, but it is a beacon of democracy and liberalism, in an age where many of the other great powers were still autocratic. But hey, if that's the case how come the same hundred families who were running the country back when Elizabeth was the queen are still running the country in the age of Victoria? That's next week on *The History of the Twentieth Century*.

Oh, and a couple more things. If you know much about nuclear physics, you've probably already noticed that roentgen, curie, and becquerel are all names of units we use today to measure radioactivity. When element number 96 was synthesized at Berkeley in 1944 it was named curium in honor of the Curies.

Marie Curie's papers are held today in the French National Library, but they are kept in lead boxes, because years of exposure to Marie's experiments have made them radioactive. If you want to look at them you have to wear special protective clothing and sign a liability waiver. Even her cookbook is too dangerous to look at without protection.

[music: Closing Theme]