Hello and welcome to Quantum Stories. A three part mini series explaining aspects of quantum mechanics simple level as part of Explorathon 2021. Episode one, The Failure of the Classic. Let me introduce myself. I am Callum Duncan, a postdoc in the physics department at the University of Strathclyde.

I work in the field of quantum mechanics. Well, more precisely, in the area between the fields of quantum mechanics and the solid state. But please don't hold that against me. I've studied physics going on 11 years now, starting with my undergraduate through a Ph.D., and now finishing my second year as a postdoc.

Maybe some of you listening do not know what a postdoc does. Research is in most cases led by professors. And most of you are probably familiar with the fact that the professor trains people to complete PhDs. Well, a postdoc is in the middle.

I'm probably far too experienced now to be someone's trainee. But I'm not quite at the level of mastery that someone like a professor is. In this mini-series, we will explore several topics in quantum mechanics. We will not dodge the big issues.

I will always give a simple explanation as close to the truth as I possibly can. I say as close to the truth as I can, not because I'll be lying to you at any point, but some of the concepts we will tackle are really mathematical concepts.

These can be difficult to truly describe in words. As a theoretician, I'll be itching at points to get a blackboard out and write equations on it to explain these concepts, thankfully, and to the delight of many, such a blackboard format is not possible in an audio medium.

Indeed, this is the reason I picked this medium, as quantum mechanics is notoriously mathematics heavy. We will instead focus on some of the stories. As any student who has worked with me can testify, I'm fascinated by stories. They are what draw me to many things, including physics.

So hence the name of this mini-series, Quantum Stories. We will start with a brief history lesson of how quantum mechanics came about. The full history of quantum mechanics is a long and fascinating one. It includes some of the standards of TV dramas, controversies, arguments, success, failure.

It really does have it all. I'm afraid we will not have time during this mini-series to go through this long story. It's a bit more than I can manage to produce at the moment. But this mini-series will attempt to explain some of the most important aspects of quantum mechanics.

In this episode, we will briefly explore one of the most important stories, the failure of classical theory. First off, I want to say that classical theory to this day is truly not a failure. It still governs most of our understanding of the world around us and has probably the biggest effect on our everyday lives.

To say that classical theory failed is the easiest way to explain the birth of quantum mechanics. But we should always be honest. The truth is the classical theory failed to understand certain observations at the beginning of the 20th century.

And in order to understand these observations, a new framework or theoretical understanding was developed. Like any story you hear, always think about who is telling it to you. I have something to gain by telling you that classical theory failed.

I work in quantum mechanics and I have bills to pay. Part one, the success of the classics. Like many good stories, we start in an exciting time where many were happy and things were going well. The 19th century.

OK, I really am just talking about physics here, people were happy in physics, at least how we perceive it today. The 19th century was a time of major leaps forward in our understanding of the world. Italian physicist Alesandro Volta invented the battery allowing for electricity to be stored.

English physicist Michael Faraday and German physicist Georg Ohm made discoveries which led to the possibilities for the basic electric motor. Connections were also being made between heat and mechanical energy. All of these are cornerstones of our electricity production to this day.

Scottish mathematician James Maxwell was formulating his famous set of equations which form the framework of our understanding of electricity and magnetism. Maxwell also contributed to the revolutions sweeping through for theoretical physics at the time. No, not quantum mechanics.

Not quite yet, but statistical mechanics, which was most famously studied by Ludwig Boltzmann and Josiah Gibbs. Statistical mechanics had success after success, but all was not as cheery as it seemed. On the horizon, a dark cloud was approaching.

The cloud first came to rain over the topic of blackbody radiation, where our story will now turn. Part two, blackbody radiation. A black body is an object which absorbs all incident light, or to be more truthful, all electromagnetic radiation.

However, this truth is not critical for the story, and we will progress through with talking about light and electromagnetic radiation somewhat interchangeably. A white body is an object that does not absorb all incident light. When talking about light it's simple to recognize such objects about us in our everyday lives as it is what gives a lot of things colour.

What we observe as the colour of the object is light reflected. So it is the light that is not absorbed. We can define a quantity that tells us the absorption fraction of an object. If this object is a black body, then it's absorption fraction is one, meaning it absorbs all incident light.

If an object is not a black body, say, a pink toy train my daughter is currently learning to walk with. Well, for this the absorption infraction is most definitely not one. In fact, for this pink toy train, the absorption fraction is not the same for different colours or more technically frequencies of light.

But it will not surprise you that physicists at the beginning of the 19th century were not interested in investigating my daughter's toy train. Even if its songs are loud enough to penetrate through the ages. Instead, physicists were interested in investigating further

one of the successes of classical theory, the understanding of the relationship between heat and energy. If we have a box that is at some temperature, then we all know that when we touch that box, we feel that it is hot or cold,

when what you're feeling there is some of the electromagnetic radiation that is being given off by this box. Another great example is the sun, which is emitting light and heat as part of its blackbody spectrum. The blackbody spectrum is the collection of light that an object produces.

Back to our box. If I have a box that is a certain temperature and I had another different box of the same temperature. Well, it's not a surprise that we should expect the blackbody spectrum of both to be the same.

In other words, we expect at any given temperature, our two boxes will emit the same light or the same electromagnetic radiation. In other words, the blackbody spectrum is universal. This all sounds good and makes sense, no? In the closing decade of the 19th century, this universal distribution, the black body spectrum, was measured in a series of radical

experiments in Berlin. All still sounds great, right? Now, the poster child at the time of theoretical physics comes in. We've already met them, statistical mechanics. In a series of papers, John Strutt and James Jeans attempted to understand the measured universal distribution

of the black body spectrum through the framework of statistical mechanics. This gave some promising results. They managed to arrive at a form of this universal distribution, which agreed with some of the values measured. But there was a big issue.

After a certain point, the theory would blow up in a way that only a mathematical equation can. Their theory predicted that if you went to higher and higher frequencies of electromagnetic radiation, that the amount of radiation from those higher frequencies would be tending towards infinity.

It would grow and grow and grow. This was not correct. It was dubbed the ultraviolet catastrophe. Part three, the call for a new theory. The correct distribution for the black body radiation was obtained by Max Planck in nineteen hundred.

Plank found that the distribution of blackbody radiation measured could be fitted with a certain form of a function. In order to do this Plank found that you need to multiply his equation by a constant to get agreement with the experimental results.

This constant has ever since been known as Planck's constant, and it's one of the fundamental constants of physics. At first, Planck's formula was the result of guesswork. But not long after Plank succeeded in deriving the formula by making a radical assumption. Plank assumed the radiation was related to many charged oscillators.

At this point, it was well known that a charged particle oscillating would produce radiation, basically Planck assumed that each oscillator oscillated at a frequency. And that its energy was given by Planks constant times this frequency. Plank had therefore quantized the energy of the oscillator.

The oscillator was only allowed to have an energy which was a number times the Planck's constant. In other words, the energy could only take discrete values. Think going up a set of stairs, you've got one stair, then the second stair and so on.

The number of stairs is discreet. There's no such quantity as saying you went up half a stair. The discretization upstairs is the same as the discretization of energy by Plank. These discrete amounts of energy were named "Quanta" by Plank, which is the Latin word for "how much".

Hence the birth of quantum mechanics. Part four, the long way home. As any parent will tell you, those moments when your child is born are amazing, confusing and tiring. Time in the hospital is an interesting adventure, where you are normally learning new things and coming to terms with being a parent.

Then you leave the hospital and you feel like it's official. You're a parent, your child has been born. It's time for a new adventure. Your world and life are never the same again. Everything changes, and understandings you thought you had gained before are gone.

I think being a physicist involved in the birth of quantum mechanics must have felt similar. You're taking a logical next step, answering the interesting questions, solving the blackbody problem, for example. Then suddenly you're leaving where quantum theory has been born into living with quantum theory.

I wonder how aware those physicists were at the start, did they have similar feelings of exhaustion, delight and discovery that I had as a new dad? First thing to now mention was that Plank's derivation, while beautiful with the oscillators, was not conceptually the full story.

Planks work was all to show that matter could emit and absorb quanta of radiation, but this did not mean the radiation itself was discreet. A famous remark was the Plank's what radiation was like, butter. Butter comes in any quantity but can only be bought in multiples of a quarter pound.

The real revolution began when Plank's findings were turned on their head and it was realised that radiation or light comes in quanta as well. Join us next episode to move away from the history books and discuss some of the quirks of quantum mechanics.

We will explore the ideas of waves and particles and then show that the line between the two is much blurrier than you may expect. I would like to thank the Explorathon team at the University of Strathclyde for their support in attempting this mini-series.

I would like to thank you for listening and hope you will join me again in the future.