Introduction

Hi everyone! This is episode eleven of the Metaphysics of Physics podcast.

I am Ashna, your host and guide through the hallowed halls of the philosophy of science. Thanks for tuning in!

With this show, we are fighting for a more rational world, mostly by looking through the lens of the philosophy of science. We raise awareness of issues within the philosophy of science and present alternative and rational approaches.

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Today we are providing an overview of the achievements of the great Isaac Newton, focusing on his contributions to science. At a later stage we will go over what made him such a great scientist.

This will be the first of our coverage of great figures in the history of science. With some more coming later this year. But, without further ado, let us start our discussion of the achievements of Isaac Newton.

We have a lot to cover, so we cannot cover any one aspect of his work in great detail. Nor can we cover all of his extensive contributions.

Some of them we will not go into detail on. Some we will not cover at all. Such as his work on cubic functions, infinite series, harmonic systems, Diophantine equations, finite differences and more.

We will cover some of the more influential aspects of his work. Starting with calculus, working our way to his other mathematical contributions and then working forward from there.

Calculus

One of his greatest works for which he is best known, is his invention of calculus.

Now, I am aware that many people debate whether Newton or Leibniz developed calculus first. While I believe that in fact Newton may have developed it first, I am not sure whether this will ever be known with complete certainty.

And really, it does not matter much. It seems quite likely that Newton and Leibniz developed calculus independently, although Newton seems to have begun his work first.

It would not be the first time two different people independently developed important and major scientific advances at much the same time. Another classic example would be Wallace and Darwin. Both of whom developed somewhat similar theories of evolution.

Regardless of which of them developed it first or if they each discovered it independently, Newton certainly developed calculus and so he deserves great credit for that.

What is calculus? It is a branch of mathematics which is essentially composed of two aspects.

Differential calculus, which studies patterns of continuous change.

And integration, which amounts to adding up infinitesimally small values and is the mathematical reverse of differentiation. Calculus is the underpinning of much of modern mathematics and without it much of modern mathematics would not be possible.

As differential calculus studies things in motion, it is a fundamental underpinning of the physics of moving objects. Or indeed any quantity which changes continuously over time.

In fact, much of Newton's physics depends on and was derived using differential calculus. For instance, you can use calculus to derive an equation for acceleration from an equation for velocity.

Now, just how important is calculus? Well, it is very hard to overstate the importance of calculus. It is one of the most important, widely applicable branches of mathematics ever invented.

Why is this? Because it can be used to describe the behaviour of virtually anything that moves or changes over time. Which is to say, virtually anything at all.

You can use calculus to describe the velocity of a space rocket. Or how stock markets change over time. It can be used to study the equations and or graphs that describe phenomena. You can use calculus to find various properties of these equations and graphs. Such as the rates of change and optimal values and the list goes on.

Calculus is used in countless optimization problems. In such problems you take equations that describe relationships between certain variables and you find the value or values of those variables that give you the optimal results.

Suppose you have an equation that describes the amount of material used to create containers of a certain volume. You can use calculus to find the dimensions of a container that will hold 1.5 litres but which will minimize the amount of material used.

That's litres (leeters) not litters, though I guess you could find out how many litters of kittens you can fit in a container, using calculus too!

A great variety of problems where you want to maximize or minimize some quantity can be solved using calculus. For example, problems which are very frequent in business and/or design where efficiency must be maximized and cost minimized.

That is differential calculus.

Integral calculus also has many applications. One of them is finding areas or volumes. For instance, if you want to find the volume of an irregular shape such as a Coke bottle, you can use integration to do so.

Many properties in physics are calculated as integrals. For instance, finding the coordinates of the centre of mass of an object, studying magnetic flux and so forth.

And then there is the fact that since integration is the reverse of differentiation, you can use it to derive many equations, just as you can using differential calculus.

The applications of calculus are far too numerous to mention all but a few of the most general applications. Suffice to say that every branch of higher mathematics uses it and calculus is applicable to almost any field of knowledge known to man.

Which is true of mathematics in general, right? Mathematics is all about describing and deriving the various relationships between entities and their properties.

Well, calculus is a fundamental technique used to find many of these. Without which much of higher mathematics would not be possible.

Newton-Raphson Method

This is a method of numerical analysis which allows one to find approximate solutions for real-valued functions. That is, mathematical functions with solutions that are real numbers.

Yes, it has been generalized to complex values, but we will not go into that here.

Let us suppose that you have the equation $x^3 + 5x - 3$ = zero. What value of x satisfies this equation? The Newton-Raphson method allows an approximate value to be found.

It is an iterative process, requiring repeated cycles through the Newton-Raphson formula in order to get increasingly accurate results.

This is not the only such method used to solve functions. But, it is a commonly used one and some computer algorithms use it to solve functions.

But why should we care? Well, many equations where you need to solve for x can be solved with the Newton-Raphson method. In fact, many equations where we have no known method for finding exact solutions can have this method applied. This allows approximate values to be found.

You can also use it for optimization problems, similar to the optimization described when we discussed calculus. In fact, the Newton-Raphson method itself uses calculus, differentiation in particular.

Its applications are many and varied. It is frequently used in the analysis of flow in large networks. Such as water distribution networks or electrical flow through electrical grids.

It also has various uses in numerical analysis and other areas of mathematics, but we will not go into that. Suffice to say that it is an extremely important tool in solving and analysing a great many equations.

Binomial Theorem

This mathematical theorem involves the expansion of powers of binomials. A binomial is something like “X squared plus 2”. Basically, the binomial theorem deals with some variable plus something else, all to the power of something.

These powers of binomials can be written in their full form as a polynomial. Such as x squared plus 5x + 3.

Let us suppose you have something like "2x +3". And you want to multiply it by itself, you have this:

$(2x+3)^2$

You get a polynomial like this:

$4x^2 + 12x + 9$

The binomial theorem lets you find these polynomials.

So, if you want to multiply (2x + 3) by itself 5 times, what do you get? Well, the binomial theorem will tell you that.

Which is good, because the polynomial will look something like $32x^5 + Nx^4$….etc. Calculating this by hand would take a while.

Now, it should be noted that others, including Euclid and Al-Karaji had developed less generalized methods for doing this kind of thing. However, Newton's method was more general. It could also be applied to all real numbers, as opposed to only nonnegative integers.

But, so what? Of what importance or application is this to the real world? Well, quite a lot as it turns out.

Every computer on most networks, including the internet, has an IP address. This is essentially a unique number that is used to identify your particular computer on the network (I am over-simplifying a bit but the fine details do not matter that much).

Well, these are often automatically assigned and the binomial theorem helps to do that. The binomial theorem can deal with other such network problems.

It is also used in estimating probabilities in fields like economics and weather forecasts.. It is used to help design infrastructure to help find the proper amount of materials to use. As well as that, it also helps rank things. And so on….

Motion

Newton is best known for the legendary book Philosophiæ Naturalis Principia Mathematica (Latin for Mathematical Principles of Natural Philosophy). Here he sets down the sum total of his considerable discoveries in mechanics.

This is a rigorous presentation of his well-known laws of mechanics and his theory of gravitation.

His law of universal gravitation states that everything in the universe attracts everything else in the universe with a force which is directly proportional to the product of their masses and inversely proportional to the square of the distance between their centres.

He used his theory of gravitation to prove Kepler’s laws of planetary motion, account for the tides, the trajectories of comets, the precession of the equinoxes and more.

He demonstrated that the motion of objects on Earth and celestial bodies in space could be accounted for by the same set of principles. This finally made sense of the heliocentric model of the universe and explained Kepler's astronomical observations. Thus dismissing any serious doubt of the heliocentric model.

This was a crucial moment in physics! The importance of providing a single set of principles which explained the behaviour of both Earthly and celestial bodies can hardly be overstated.

Before Newton, it was customary to view the Heavens as a strange place very different from the Earth and not subject to the same kinds of laws. But Newton helped change this by showing that in fact the heavens and the Earth obeyed fundamentally the same equations.

This greatly demystified the heavens and helped to make the point that physic was a truly universal science which could explain everything, even the heavens.

But what about his other laws of motion? Chances are that if you have a science education, you have encountered these laws, even if you can’t remember them offhand. They are very simple laws which can be very easily understood and used by school children.

That is part of their beauty. They are not the sort of complicated, difficult to work with equations that take considerable mathematical expertise or computational tools to deal with. Which is more than can be said for several other equations in modern physics.

But, surely the worth of a theory is not in how elegantly simple to work with its mathematics is. Several aspects of the mathematics of quantum theory is much more difficult to work with. But that does not make it any less true or important. Regardless of what we think of the interpretations of the mathematics of quantum theory.
If you are dealing with something that moves, at least something that does not move at an appreciable fraction of the speed of light, then Newton's Laws of Motion are bound to be relevant. You can use them to understand the behaviour and trajectory of the objects in question.

In fact, the motion of virtually everything we deal with in normal life can be understood in terms of Newton’s Laws of Motion. Without them, the motion and behaviour of a great many objects in our world could not be properly understood.

They serve as the basis for much of physics, certainly much of the branch of physics known as mechanics. And have been important in several other branches of physics.

Until they were superseded by Einstein's Relativity, his law of gravitation were used to understand the motions and behaviour of much of the celestial objects in our universe. Without an understanding of gravity as provided by Newton or Einstein's equations, the behaviour of most of the objects in space cannot be understood.

But, the importance of this goes far beyond providing an understanding of the motion of Earthly and celestial objects. Newton was one of the first to show that many aspects of nature can be easily understood by the application of simple physical principles.

Not only that, he showed that the behaviour of these physical objects could be calculated and predicted using simple equations.

This made an immense case for the power of science, physics in particular, for understanding the universe and predicting its behaviour.

The work of Newton showed just how much of the real world could be understood and predicted using simple equations. But, not only this, it showed the immense power of induction.

This was key to Newtons immense success. He was a master of grasping the commonalities between seemingly disparate things such as rocks on Earth and comets in space and identifying general principles which applied to both kinds of entities.

We will talk further about induction in a later episode. But for now note that a key reason for Newton's success at explaining so much of nature with a few simple principles, is his application of induction.

Another important aspect of Newton's laws of motion is that his theory of calculus was crucial in helping to derive them. In fact, you can, as Newton did, use simple calculus to derive various of his laws of motion from previously established ones.

This illustrates the vital role mathematics plays in physics. Mathematics is the science of quantifying relationships between things. Physics of course deals with many such relationships.

What Newton did was start with something he knew to be true, such as his Second Law of Motion, and perform mathematical operations so that a consequence of this is that F equals mass times acceleration.

Now, this itself does not prove that force equals mass times acceleration. But it suggests that this might be the case. You can form a hypothesis that it might be so, one you can test to show that indeed, force does equal mass times acceleration.

So, mathematics helps to identify relationships, which can help you formulate hypotheses to test and thus help develop theories in physics. Not just physics, but almost anything else.

This is how Newton worked and Principia masterfully shows how mathematics can be used to tease out the implications of your theories.

It also once more shows the vital role of calculus. Without which, Newton would not have been able to discover many of the Laws of Motion.

Optics

Newton observed that a prism refracts different colors of light at different angles. Which led him to conclude that color is a property intrinsic to light. Something which was then and is still sometimes hotly debated.

He then investigated the refraction of light and demonstrated that the multi-colored spectrum of light produced by shining light through a prism could be recomposed into white light by using a lens and another prism.

This showed that white light was in fact all the colors mixed together and that the prism merely served to separate them.

He was thus the first to understand the rainbow as the result of light being separated into different colors. Rain drops work rather like a prism. White light enters raindrops and the rain drops act much like a prism, separating out different colors and thus producing the range of colors seen in a rainbow.

He then proceeded to show that color is the result of objects interacting with colored light rather than objects generating the color themselves.

Now we know that each color from the visible spectrum of light has a specific wavelength. And that the color of an object is determined by the wavelengths of light that gets reflected or absorbed when interacting with the object.

Newton’s work helped set the stage for this understanding and our understanding of how color and vision work.

His findings led him to conclude that colour is a property of the light, not a property of the objects themselves.

Before this it was customary to assume that color is an intrinsic property of objects. As if an apple is red because of some inherent property of redness in the apple. Or that the sky is blue because it has a inherent blueness property.

Newton's experiments show that this is not the case and that colour is a result of the interaction of entities with light.

Red apples are red because their nature is such that when light interacts with it, the wavelengths of light that get reflected or transmitted are the wavelengths from the red spectrum of visible light.

The sky is blue because of the way light interacts with the particles in the sky. Not because the apple has the property of “being red” or because the sky has the property of “being blue”.

Redness is not “in the apple”, nor is blueness “in the sky”. Colors are not properties of the object. They are a result of the way the object interacts with light.

All these discoveries about light, served as the basis for our understanding of how light interacts with objects and what color is. As well as what light is, at least for a time. But what did he think light is?

He argued that light is composed of particles or “corpuscles” which were refracted by accelerating into a denser medium . This was dominant for about 100 years, but was eventually superseded by a wave theory of light.

However, light currently occupies a weird limbo state. It sometimes seems to behave like a particle and sometimes like a wave. It cannot be both, so there must be some explanation which would explain this apparent contradiction.

Newton's particle theory of light may yet prove to have some truth to it.

There is of course more to the concept of colour since we have not discussed the role of sense perceptions yet. But let’s not steal the light from Newton, we will cover this in another blog post in the future.

For instance, if redness is not in the apple, is it in the light? While we can separate white light into different colors using a prism, does this mean that those different colors are intrinsic properties of light?

Reflecting Telescopes

Newton built the first practical reflecting telescope, also known as the Newtonian telescope or the Newtonian reflector.

Although it was not the first telescope, it was the first practical telescope to work on the principles of reflection of light. Previous telescopes, such as those Galileo built in 1609, were refracting telescopes.

Refracting telescopes work by using lenses bending light rays and causing them to converge at a focal point, thus producing a magnified image.

However, reflecting telescopes work differently. They use a combination of curved mirrors to reflect light and form a magnified image.

One major advantage of a reflecting telescope is that it is free from the severe chromatic aberration of refracting telescopes.

A chromatic aberration is caused by the failure of the lenses in refractive telescopes to properly focus all colors of light to the same point. This results in a blurred image and colored edges.

Newton realized that the lens of any refracting telescope would suffer from the dispersion of light into colors. Which is what causes chromatic aberration.

So, he invented the reflective telescopes, using mirrors to correct this problem.

Most telescopes used today are reflecting telescopes. This is because they are not subject to chromatic aberration, although they do suffer other problems.

They also can be used to help combat the disruptive effects of atmospheric turbulence, which is great for Earth-based telescopes.

It is also easier and cheaper to produce the mirrors used by reflecting telescopes than it to make the lenses used by refractive telescopes.

They are also generally more portable and compact.

They have other advantages, as well as disadvantages. Their disadvantages include the fact that their mirrors require more careful handling than their refractive counterparts. As well as the fact that their mirrors may need occasional readjusting.

But, by and large, reflective telescopes are very commonly used. Various space agencies, including NASA have employed many reflecting telescopes and they are very popular among amateur telescope buyers.

Newton’s Law of Cooling

This theory provides an empirical formula for calculating the rates of cooling. The law states that the rate of cooling of a body is directly proportional to the temperature difference between the body and its surroundings.

This can be used to find the rate of cooling of objects or how long it will take to reach a certain temperature.

You could for instance calculate the temperature of a cup of tea. Or how long it would take an ice cube to melt given its initial temperature.

If finding the temperature of cups of tea or figuring out how long it takes to melt ice do not sound very important, then the Law of Cooling has many other more interesting and important applications.

For instance, it has been used in forensics in estimating the time of death of a body some time after death. It is used to help maximize the efficiency of designs of heating/cooling systems such as solar heating systems. And many other things where it is important to understand changing temperatures over time.

This too involves elements of calculus and is yet another example of the myriad uses of calculus. And the kind of relationship you can discover using calculus and some careful reasoning.

The “Perfect Coin”

Newton was Warden of the England's Royal Mint and was thus responsible for trying to minimize the counterfeiting of English coins.

Counterfeiting was a major problem. In the late 1600’s, England’s financial system was in dire trouble. England's’ currency was composed of silver coins. The coins value was often worth more than the assigned value of the coins.

This led to people melting down or clipping silver from the edges to sell to France. As a result, many of the remaining coins were a badly damaged mass of unrecognizable silver chunks. Which was good news for counterfeiters, as it made it very easy to pass off some very non-coin like objects as coins.

So what did Newton do to solve this problem?

He went undercover, investigated, and apprehended the counterfeiters himself. This drew him to many different corners of Britain in his zeal to stamp out the illegal activity. So, basically, Newton when out and acted as a kind of Batman, investigating and apprehending counterfeiters.

Armed with a good understanding of all this counterfeiting activity, he recalled all the coins and had them melted down and reforged into a new design.

This was a pretty bold move, considering the entire country had to go without coins for an entire year. The result was a higher-quality coin with a harder to counterfeit design.

How did this work? Well, the coins you have in your country likely have those grooves/ridges on them that many coins in many countries have. Newton introduced this so that that it was impossible to mill the coin without it being detected. Thus, greatly reducing the counterfeiting of silver coins.

A simple thing, but very effective.

Conclusion

Alright, that covers most of his more interesting or significant contributions to science and one more interesting contribution to justice. As mentioned at the start, this is not an exhaustive list, but a brief overview of his considerable contributions.

How might one sum them up? Well, he created one of the most important mathematical techniques yet created, calculus. He helped prove the immense power of induction combined with mathematical reasoning. And how these can help one discover a great deal about the world around them.

He helped create physics as a true science. Before him, physics, as a field of study of the fundamental nature of reality, conducted through experimentation and reason, was largely non-existent. He helped show the universal power of what would come to be known as the scientific method and helped usher in physics qua science.

His scientific contributions, especially in the field of mathematics, mechanics and optics were immense. Enough to make him one of the greatest scientists ever.

But, I think his greatest legacy was his philosophical legacy and the impact he had on the world. How his work helped transform the world and do so much to create physics as we know it is today. Or at least, as it was known until the late 19th century.

His philosophical legacy can hardly be understated. But, we are not here to discuss that at any great length today. That will be the topic of a future episode.

Outro

That brings us to the end of this episode. I hope you enjoyed our brief coverage of the great scientific works of Sir Isaac Newton.

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You are welcome to send in questions about any of the things talked about in this episode or about irrational stuff in physics or the philosophy of science in general. Send them to questions@metaphysicsofphysics.com.

Thanks for listening! Please tune in for the next episode and start thinking of some questions! Until then, stay rational!