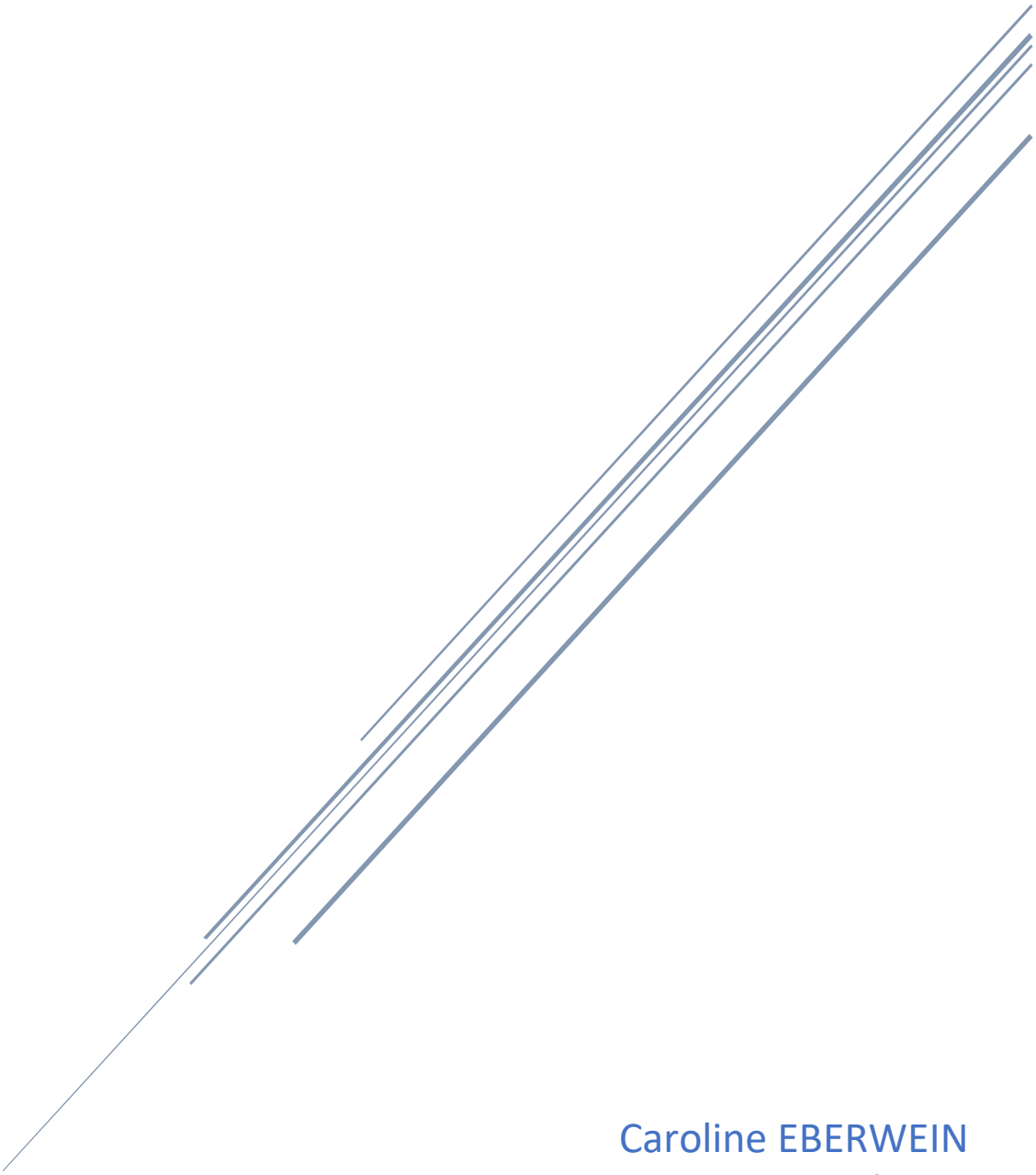
HOW ACCURATE IS THE SCIENCE IN SUPERHERO MOVIES?

THE SCIENTIFIC ACCURACIES IN SUPERHERO MOVIES



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1. Introduction

Movies have fascinated me from a young age, fuelling my wish to be an actress. The worlds and the characters depicted had me glued to the TV screen and every time I felt as if I was truly part of that world. No matter how unrealistic, farfetched or even ridiculous a concept or an idea was, in my imagination it all made sense.

Later the world of superheroes joined my fascination for movies, and they continued the ability to completely engulfing me in a foreign fantasy world. Like everyone in the world, the laws of physics or any rational explanation of the so-called superpowers were not important to me and all that mattered was how it was portrayed in the movie. Again, if it was realistic or simply nonsense was irrelevant.

After discovering my love for the link of science and the Lord of the Rings series, I started second guessing superhero movies as well with the curiosity if the depiction of these superpowers could be logically explained based on our current scientific knowledge. I did not do this will ill intentions of accusing the filmmakers of selling its viewers a lie, after all they are fantasy movies, but I was simply attempting to form a link between science and complete imagination.

In this memoire, I will pick various superpowers and scenarios in movies or comics that have fascinated me, and I will try to explain these with physics, biology or even a mix of multiple branches of science. Based on the fact that I am not a scientist, this will include various studies from published books or scientific articles on this topic and none of my own non-existent research. Included are three examples of the Marvel Cinematic Universe and the DC Universe. These are currently the leading franchises in the topic of superheroes and have collectively released more than 35 movies. The majority of my environment is familiar with their work, and I truly believe that this memoire could not only be interesting to science fans but also superhero fans who simply want to explore further behind the movies and comics.

2. Marvel Cinematic Universe

2.1 Thanos - Infinity Stones

The infinity stones first appeared in 1972 in Marvel Premiere #1 as "Soul Gems" and the first infinity stone was later introduced into the MCU in the movie *Thor* as the tesseract (Space Stone). Since then, they have been a major part of the MCU, especially in the movies *Avengers: Infinity War* and *Avengers: Endgame*. These six stones (Soul Stone, Power Stone, Time Stone, Mind Stone, Space Stone, Reality Stone) have a variety of different properties. One can manipulate time while the other one can seemingly control any object. How much of these infinity stones can be explained by science and what is simply fiction?

In the movie *Guardians of The Galaxy* the Collector explains that "before creation itself, there were six singularities. Then the universe exploded into existence, and the remnants of these systems were forged into concentrated ingots… Infinity Stones." The infinity stones are physical manifestations of symmetries and conservation principles.

Singularities are where a function is undefined or when a quantity becomes infinite. Like for example gravitational singularities, which occur when the quantity used to measure the curvatures of space-time becomes infinite in a way that does not depend on the coordinate system. At this point all physical laws are indistinguishable from one another, where space and time are no longer simply connected realities, but merge indistinguishably and do not have any independent meaning anymore. Another example of a singularity is the initial state of the universe, before the Big Bang. The infinity stones are singularities that are compressed into the physical form of a gem or a "stone."

Adding to that, the infinity stones are physical manifestations of symmetries[1] and conservation principles. In 1915, Emmy Noether, a brilliant mathematician of her time, developed the Noether's Theorem and provided a profound insight into the physical universe. She proved that the Conservation Laws of Physics[2] (Conservation of Energy, Conservation of Momentum, Conservation of Electrical Charge, etc.) are direct consequences of symmetries of the physical equations that described the universe.

It is the fact that the equations of physics do not depend on what time an experiment is performed, and that fact is reflected in the Principle of Conservation of Energy, and that the equations look the same no matter of one's location in space is reflected by the Conservation of Momentum.

Reality Stone

The Reality Stone grants its user absolute control over the fabric of reality itself with its primary power being matter alteration. The stone holds a massive amount of power in the comics with it being able to permanently reality but in the MCU it is limited to a lot of functions in local areas, such as but not limited to the ability to manipulate matter and

[1] A symmetry of a physical system is a physical or mathematical feature of the system that is preserved or remains unchanged under some transformation.
[2] A conservation law says that a particular measurable property of an isolated physical system does not change as the system evolves over time.

simulate different events. It is discussed if the stone has permanent or temporary effects in the MCU, but no clear answer has been found yet.

To find a physics interpretation on how the stone is able to alter matter we have to deal with the quantum realm. In the MCU the quantum realm is a dimension in the multiverse that is so immensely small that it can only be entered by magic, Pym Particles or a Quantum Tunnel (seen in *Antman & the Wasp*). For us the quantum realm is any universe where the laws of quantum mechanics are valid.

The field of quantum mechanics, which physicists developed at the beginning of the 20th century, describes the properties matter/atoms and light and how they behave at the miniscule atomic scale. Quantum Mechanics is itself a subject of possibilities and usually cannot predict with certainty what will happen, but only give probabilities. For example, no matter how much a quantum particle is prepared or how carefully experiments upon it are arranged, it is impossible to have a precise prediction for a measurement of its position and at the same time for a measurement of its momentum.

One proposed interpretation says that an infinite number of parallel universes exist and that all probabilities of particular quantum event are reflected in the alternate events and happening of these parallel universes. Some of these parallel universes may resemble ours while others could be outside of the realm of our imagination.

Another one of the explanations offered for the functioning of the reality stone is that it enables its user to change matter to the desired matter that exists in the multiverse and in another world. That also explains why in Avengers: Infinity War Gamora and Drax change back to their original form after being transformed by Thanos.

Time Stone

The Time Stone grants its user the ability to time travel, as well as the ability to slow down or speed up time. The stone is among the most powerful artefacts in the MCU and can only be held by beings with exceptional strength. The use of the stone is well depicted in *Doctor Strange.*

The ability to slow down or speed up time is easier to explain and comprehend and has to do with gravitational time dilation. Time dilation causes the passing of time to be experienced in different rates in different frames of references. The extremely string gravitational field surrounding a singularity causes time to slow down near it. This phenomenon can also be observed near a black hole. The Time Stone could therefore have the ability to change the gravitational field of its near surroundings without affecting its wearer and changing the gravitational pull towards the planet. But how does the Time Stone allow Strange to use a form of clairvoyance?

The ways of the Time Stone seem to be consistent with a causal timeline, so any actions or changes that happen through or due to time travel remains congruent with all outcomes that occur onward. The most logical way to confine such a timeline is to keep it in a small bubble of time-space irrespective of time. He does this for example in *Avengers: Infinity War* where he confines his use of the stone to his close surroundings. The Time Stone may give Doctor Strange the ability to create a closed timeline curve (CTC) in his current fixed point in time and space. A CTC are a curved world line (world lines are the paths travelled by an object in four-dimensional space-time; world lines cannot be called orbits or trajectories

because they are not three dimensional.), which eventually end up at the same coordinates in space-time. Thus, something that could be compared to a circle is formed. These universe lines are probably formed through frame dragging. A CTC considers an object such as Strange wearing the Time Stone within four-dimensional time-space, and they follow a world line that tracks their space together through physical space and then traveling through that space in time. Their world line defines their movements through time-space going in one direction while time moves forwards. If the Time Stone were able to generate an incredibly large gravitational field, and thus due to Einstein's predictions about general relativity, this strong gravitational force could cause frame dragging and it could bend the curvature of time space. It would allow Strange to stay in their stationary bubble of time produced by the Time Stone while the gravitational forces could be bending time-space to create a CTC where their world line would go into the future, curve around, and return to the same place 16,000,605 times. The manipulation of CTCs and therefore world lines could also allow for time travel or time loops.

Power Stone

The use of the Power Stone was best portrayed by Thanos brings down an entire moon on Iron Man in *Avengers: Infinity War*. The Power Stone is having such power that it can only be wielded by someone of incredible strength. Those who aren't strong enough are disintegrate into a purple explosion of uncontrollable energy if they try to grab it.

To measure such a large output of power, nuclear reaction is one of the most power reactions that produce energy. Energy is governed by Einstein's famous equation: $E = mc^2$ (E = energy, m = mass, and c = speed of light). Every element we know has an atomic number that is equivalent to the number of protons and an atomic number that is equivalent to the number of protons and neutrons. The mass of a proton is considered equal to the mass of a neutron and the atomic mass is two times the atomic number. The latter unfortunately does not add up. The small difference between the two number is called the mass defect and represents the mass (m) that is transformed into energy that holds neutrons and protons inside the nucleus of the atom (E). This energy is calculated by using $E = mc^2$. If an element changes the composition of its nucleus, it has to give off that mass defect in the form of energy. The Power Stone allows its wearer to manipulate the nucleons of an element and generate fission and fusion reactions. Fusion is when atoms fuse as seen with hydrogen fusion inside of the sun and fission is when larger atoms split into smaller ones as seen in uranium-235 decay in nuclear reactors. Thanos could use the Pawer Stone to change the nucleon of any atom in any element around him and then carry out a nuclear reaction.

Space Stone

Throughout the MCU, the ability universe-spanning space travel is facilitated by the Space Stone by simply opening a wormhole between the wearer's current location and the desired place. For example, when Thanos destroys the Tesseract, and he sets the Space Stone in the Infinity Gauntlet, and he is granted the ability to instantly open portals to various places.

The science considered for the Space Stone was proposed as an Einstein-Rosen bridge by S.H.I.E.L.D. agent Phil Coulson and Bruce Banner. Firstly, we have to understand the formation of black holes. After a large star collapses the black hole is what is left and it is a point in spacetime that generates so much density that gravity sucks everything into it, even

light. Einstein's theory of general relativity says that due to the mass and density of a black hole, it can create an infinitely dense singularity or a wormhole, a path to another point in time-space. The exit of this wormhole is called a white hole, where contrary to the black hole, matter travels outward similar to the expansion known as the Big Bang. Unfortunately, these wormholes are extremely unstable and would instantly collapse.

The Space Stone may have the ability to facilitate the opening of a wormhole by having to exert another force to keep it open. One possibility would be a constant stream of negative energy that is funnelled into the black hole to keep it open. That stream would repel gravity from closing the wormhole and sustain a long enough opening for it to be traversed.

Mind Stone

To explain the abilities of this infinity stone we will base its powers on the fact that Wanda Maximoff's powers were derived from the Mind Stone and therefore a diluted form of the capabilities of the stone. This can be seen when one considers that the Mind Stone can control a subject for days, whereas the effects of Maximoff's powers are short-lived and more mood-altering.

One proposed theory based on the comic books and the nature of many infinity stones, is that she is able to generate powerful and localized magnetic fields through the movement of her hands. The theory is based on the already existing non-invasive procedure of transcranial magnetic stimulation (TMS) that is used to stimulate or block activity in different parts of the brain. The functions of electricity and magnetism are actually two different forms of the same phenomenon. For example, an electric current run through a coil can create magnetic fields and a strong magnetic field can modulate an electric current. During TMS, a strong electromagnetic force is targeted toward the surface of the brain to depolarize neurons in that area, which then leads to increased activity. Scarlet Witch could be able to create a "coil" with her bizarre hand movements that conducts enough current to create a localized magnetic field that is completely under her control. This coil can be used to electromagnetically create a current through the skull of her victim, inducing an oppositely directed current in neural populations within the brain. Maximoff would need an incredibly deep understanding of neurology to properly influence the right areas and neurons, but one can assume that the powers given to her also gave her this knowledge. Due to this knowledge, she is able to elicit a range of behaviours and the power could be even more potent if she could shrink the magnetic field to only focus on a single neuron. However, a stronger magnetic field would allow for deeper stimulation.

For example, during Tony Stark's hallucinations, she may have sent a wave into multiple layers, triggering the release of neurotransmitters and therefore his PTSD. This could have had the rippling effect to other parts of his brain, forming connections between auditory, visual, and somatosensory cortices[3] and therefore making it seem as if the hallucination is real even though it is not.

The Mind Stone could work in similar ways and with the same principle but to an extent that is currently unknown. It could also create localized magnetic fields that are even more powerful and long lasting that Scarlet Witch's current ones. The basic principle is that all mental processes are electric, and if one could manipulate these with electricity, one could

[3] explanation

also control a brain's functions. And this is exactly what the Mind Stone and Scarlet Witch are doing.

Soul Stone

The Soul Stone who as to be obtained by the sacrifice of a loved one, has the ability to manipulate the soul, the very essence of an individual, and has the ability to resurrect and conjure the spiritual representation of the dead. This is something that currently cannot be explained by our current scientific knowledge. Maybe in the future, when our society advances and we gain more insight into how our universe works, we will be able to explain this phenomenon, but I will stay a mystery for the time being.

2.2 Thor - Mjolnir

Mjolnir is a fictional weapon depicted as a large, square headed grey sledgehammer, with a short handle wrapped in brown leather and is based on the weapon of the mythological Thor. Odin, the father of Thor, placed several enchantments on the hammer with the most important one being, “No living being may wield it unless they are worthy.” This means that no person or creature that is deemed unworthy of the power that the weapon holds, can move or lift the hammer.

The question of how and who can raise Thor’s mighty hammer has been around since its first appearance in 1962. While a good answer may be magic based on the fact that its origin is from a fictional planet, its material made from “uru metal” and the owner of the hammer the Norse god Thor, in this memoire we are trying to find explanations based on our current scientific knowledge of our planet earth and how these objects would interact with our laws of physics.

In a scene in *Avengers: Age of Ultron* the Avengers can be seen sitting around Tony Stark’s penthouse apartment and discussing the “enchantment” of Thor’s hammer. Thor places his hammer on a coffee table partially on top of some books, and various heroes attempt to pick up the hammer, but with no success. Tony Stark (Iron Man) gets help from a glove of his suit and even multiple men together are not able lift the hammer. Thor then hefts the hammer with ease and casually flips it into the air.

Astrophysicist and Director of the Hayden Planetarium, Dr. Neil deGrasse Tyson, speculated that if Mjolnir is composed of neutron star matter which has a density of one hundred million million grams per cubic centimetre and is therefore the densest material in the universe outside of a black hole, then it would weigh roughly twelve thousand trillion pounds. In our universe it is currently impossible that a coffee table and a couple of books exist that could put up under this weight. This explanation may be logical but not supported by the circumstances shown in the movie.

In 1962 science fiction writer Arthur C. Clarke formulated his famous Three Laws, with the third law being the best-known and most widely cited: “Any sufficiently advanced technology is indistinguishable from magic”. Marvel establishes that the Norse gods in the comics and in the movies are a race of alien beings who live in a much more advanced and complex society compared to twenty-first century Earth with each god having their unique abilities that seem like magic to us and thus explicitly invoking Arthur Clarkes third law. In this case, we can speculate that the magic depicted in the MCU is incredibly advanced technology that we as humans with our current knowledge cannot yet fully comprehend. We will still try to build a solid theory based on our limited comprehension of the laws of the universe and as time goes on and more discoveries will be made and proven, refine these theories.

In the first *Thor* film, when Odin banishes his wayward son Thor to Earth, he whispers to the hammer: "Whoever holds this hammer, if he be worthy, shall possess the power of Thor." In these days of interactive, voice recognition software, such “enchantments” or reprogramming orders of the hammer’s operating system through speech commands are hardly a ground-breaking discovery anymore. The mystery that remains and that does defy present-day science is how the nanotech embedded within the hammer could execute Odin’s instructions.

In *Avengers: Age of Ultron*, Tony Stark proposes the theory that there might be a biosensor inside the hammer's shaft that recognizes when Thor picks it up. He might be partially correct, but the hammer is not reading Thor's fingerprint unlike most smartphones nowadays but most likely a complex biological and psychological profile that determines the "worthiness" of the person trying to lift the hammer. This is supported by the fact that no one was unable to budge the hammer until Steve Rogers (Captain America) is able to lift the hammer in *Avengers: Endgame*. The remaining question would be how Mjolnir prevents itself from being moved after determining someone to be "unworthy"?

The answer to this question lies within with Newton's First Law of Motion, which states that an object at rest will remain at rest, if no net force acts upon it. When the hammer rests on the coffee table, there is a downward force on it known as gravity which is the gravitational attraction between the mass of the hammer and the mass of the Earth also referred to as its "gravitational weight" and a counterforce from the book and tabletop pushing up on the hammer. This counterforce, or also referred to as a normal force (as it acts perpendicular or normal to any surface) is fundamentally electrostatic in nature, and is easy to take for granted except when it fails (for example when a multiple thousand kg object is placed on a simple coffee table that can only provide a counter force of multiple hundred kg)

When Tony Stark tries to lift Mjolnir, he exerts a large upward force, greater than the weight of the hammer that should technically be more than enough to lift a normal hammer and yet Mjolnir does not budge at all. So where does the additional downward force come from that keeps the weapon in its place?

The theory is that uru metal has the unique property to emit large quantities of gravitons on demand. The graviton is a hypothetical quantum of gravity, an elementary particle that imitates the force of gravitational interaction. Scientist have not been able to experimentally confirm the existence of this particle, but as stipulated, the Asgardian society is much more scientifically advanced than the human one. Due to the fact that Gravitons are conjectured to transmit gravitational force, if an object such as the hammer emits additional gravitons, it consequently increases its mass. Subsequently when a deemed unworthy person tries to lift the hammer and applies an upward force, the uru metal increases the hammers weight by emitting more gravitons to cancel this lift and the hammer therefore remains unmoved. The greater weight of the hammer does not damage the tabletop, because only enough gravitons are emitted to neutralize any and all upward forces, to keep the hammer placed on the table. Once the upward force ceases, the excess gravitons emission also discontinues.

Another incredible ability of the hammer is that it can alter its trajectory and move to return to Thors hand which could suggest that the uru metal is able to alter its interaction with gravitational fields. In physics, the question, "How fast is someone moving?" is always answered with, "Who's asking?" If one would be sitting on a bench at a train station, this person would be at rest, while a person sitting in a train that is speeding by would be in motion. This would be from the frame of reference of the one sitting at the train station while the frame of reference of the person sitting in the train would be that they are at rest while the one sitting on the bench is in motion. Both persons are in fact racing with a speed of 107,000 km/h as the earth orbits the sun within our galaxy, which is in turn racing through the universe. Concluding all motion is relative, so the hammers abilities must include the ability to alter its rest frame in mid-flight, so that its motion, when viewed from the perspective of a stationary observer, will be such that it returns to Thor's hand.

Thus, when an "unworthy" person applies an upward force, the uru metal increases the hammer's weight to exactly cancel this lift, and the hammer remains unmoved. When Tony and Rhodey simultaneously exert a larger upward force, the emission rate of gravitons increases, to again neutralize their efforts. The greater weight will not damage the tabletop, as only enough gravitons are emitted to balance out all upward forces, to keep the hammer stationary. Once the lifting force is stopped, the excess graviton emission also ceases.

2.3 Spider-Man - Spidey Senses

Spider-Man has numerous spectacular power such as super strength, the ability to stick to surfaces and thus crawl on wall and his unique "Spidey senses". These give him the ability to sense danger in his near environment before it even happens. For example, in *Captain America: Civil War* Spider-Man is able to spot Ant-Man on Captain America's shield, to dodge an incoming Redwing, and to catch Bucky Barnes's punch.

For humans the sense of touch is incredibly important. The neurons in our hands are mapped extensively onto our somatosensory cortex in our brain which is responsible for receiving and processing pain, vibrations, mechanical movement, temperature and a variety of other stimuli. The question with Spider-Man is how this process is regulated, how it is possible for him to perceive really subtle changes in his environment and how this is linked to spider from whom he famously got his powers? And is this also possible for humans?

To start, we are going to assume that Spider-Man is still human but has adopted the incredibly low threshold stimuli of a spider. For example, if you sense a light breeze on the back of your hand, Peter Parker would have sensed that same breeze all over his body a couple seconds sooner. Due to his peripheral nervous system being hyper-innervated[4], he is therefore hyper-aware of his surroundings. As a comparison, humans have highly innervated hands, lips, and tongue. The signals we receive there pass through our spinal cord to the somatosensory cortex of our brain, and they involve different kinds of neurons at the point where they receive a specific stimulus.

In the case of Bucky Barnes's fist flying towards Spider-Man, he was able to block that punch with his hand before Bucky Barnes had finished the motion. He was able to do this because his Spidey senses alerted him of the incoming punch. While typical humans are not able to do that, we have certain proteins in our cells that could function as electrical sensors. Kir4.2, one of many potassium channels[5] embedded in our cells could become activated with positively charged polyamines[6] in our tissues and cells. An electric force outside Parker's body, however weak it may be, could start the transport of ions inside the channel through the polarization of the polyamines and cause and electric impulse. While an electric arm may be an extreme force, it does not exclude the possibility that Spider-Man's ability cannot sense any other muscles contracting with great force since a contraction is likely going to cause an electrical activity proportional to the force that is about to be exerted. Therefore, any dangerous electrical activity could be enough to set off Peter Parker's Spidey senses.

But his sense isn't limited to electrical activity. In Avengers: Infinity War, Spider-Man's hair on his forearm stand up to alert him of danger in his surroundings. This could be explained by low threshold mechanoreception[7]. In his case, his hair follicles stand up like antennae for surrounding vibrations that are innervated by hair plexus nerve endings. For humans, the threshold for sensation on hair is relatively high but Peter Parker's brain is alerted of any however subtle surrounding movement through an electrical impulse that goes through the nerve endings around the bottom of his hair on his forearm.

[4] Excessive supply of nerves
[5] Potassium channel are the most widely distributed type of ion channel
[6] A polyamine is an organic compound having two or more amino groups
[7] Mechanoreception is the ability to detect and respond to certain kinds of stimuli in its environment

Both sensations help modulate his Spidey senses, so he is not constantly thinking that he is in danger. For example, if he detects an electrical impulse around him but no ambient movement it could just be a nearby phone charging or if he feels a breeze but no electrical activity around him this as well would not pose a threat. However, both of these sensations in conjunction from directly behind him would signal his brain to initiate a fight or flight response.

Humans react in the same way as Spider-Man but just less extreme. Since Peter Parker's hyper-awareness comes from the fateful spider bite, we can draw parallels between him and the manner in which the majority of spiders sense their environment. Most spiders have hair-like sensory organs called trichobothria, which are similar to human hairs, but each hair is innervated by its own nerve ending. This sounds pretty similar to Spider-Man's ability, but it would not help him because of the clothes he wears. Humans still have a kind of spider sense, but it is not exactly what one might expect. A study by Dr. Joshua New of Barnard College asked participants to focus on three lines and to pick the longest one over three trials. Afterwards the participants were given a quick flash of an imagine for two hundred milliseconds. The image contained a hypodermic needle, a housefly, or a spider-like circle with radiating segments. 15 % of the participants noticed the hypodermic needle, 10 % the housefly, and more than 50 % noticed the spider like shape. This is explained by the evolutionary roots of the human species in Africa, where a spider bite could have fateful consequences.

3. DC Universe

1. Superman – Heat Vision

Superman, one of the, if not the most, beloved and best-known superheroes of them all, has numerous abilities from his superstrength to the ability to fly to his most famous superpower: his kryptonian heat vision.

With its first appearance named as Superman's heat vision in early 1961 in Action Comics #275 (by Jerry Coleman, Wayne Boring and Stan Kaye), it has been many things from literally heat shooting from his eyes in form of a beam to lasers to pure energy. The source of this incredible superpower is the sun, and, in the comics, it is established multiple times that his heat vision is simply a release of absorbed energy.

To start, one must know how much energy the sun radiates and how much Superman is capable of absorbing. The Sun as the star at the centre of our solar system and is a ball of hot plasma, heated by nuclear fusion reactions in its core. Every second the sun is radiating over 100 petajoules of energy. If one could capture all this energy for just two minutes, it could power the United States for an entire year. The distance between the sun and the earth means that every square metre of the earth is receiving around 1400 Watt or 1400 joules of energy per second. The average human body has around 2 square metres of skin. If we assume that the entirety of Superman's body surface is able to absorb sunlight as well as not visible light such as UV and X rays, then Superman could be receiving 2800 watts of power. Superman's ability to absorb the sunlight and convert it into power could be compared to a superefficient solar panel that converts 100% of solar energy into energy to power his heat vision.

How long would Superman have to wait to be able to laser a building? To answer that we will calculate how much energy Superman would be able to release after 1 minute, 1 hour, 1 day, 5 days, 1 month and then 1 year. After one minute of absorbing solar power, Superman's eyes can let out a burst of 168 Kilojoules or around the same amount of energy that one of the most powerful lasers in the entire world can put out at the national ignition facility. After an hour of absorbing solar power, Superman can let out around 10 Megajoules. After a whole day, Superman would be able to release 240 Megajoules which is the equivalent to exploding 58 kilogrammes of TNT. After 5 days, he would be able to release around 1 Gigajoule of energy or like the entire energy of a lightning bold. After 1 month, Superman should be able to release enough energy to melt seven tons of steal and after 1 year, the same amount of energy as the largest non-nuclear bomb ever designed named the GBU-43 or the B Massive Ordnance Air Blast.

In the year 2015, SUPERMAN #38 included one of the greatest reveals in Superman history: A brand new Super-Power. In the story, Superman and Ulysses are engaged in a fight as Superman tries to save earth from Ulysses' vengeful destruction. Their battle reaches the ultimate climax when both super men engage their greatest energies to fight one another. Superman pushes his heat vision power to the limit, unexpectedly unleashing a massive solar flare for the very first time. He realized that he could release all the solar energy in cells at once which results in an explosion instantly incinerating everything within 400 km. How long would Superman have to wait and absorb solar energy to unleash this new

superpower? If we compare his new superpower to a World War 2 nuclear weapon with 63 trillion joules, Superman will have to save up for 713 years.

There are other ways as to make Superman's heat vision stronger or to shorten the amount od time Superman has to wait until he has the same amount of energy. For example, he could increase the surface area of his skin or fly closer to the sun. If he would stand on the planet Mercury, he would have to wait only 70 years to release all that solar energy as he does in the comics.

2. Flash – Running up a building

The origin of the Flash is very well known. Police scientist Barry Allen stands too close to an open window during a storm while standing in a chemical storeroom and gets hit by lightning and simultaneously doused by the shattered chemical containers. The conjunction of the lethal voltage and the deadly chemicals somehow only knock Allen of his feet and then endow him with superspeed. He then naturally adapts a red-and-yellow costume and uses his new superpowers to fight crime as the Flash.

In his very first Silver Age appearance in October 1956, *The Mystery of the Human Thunderbolt* in Showcase # 4, the Flash ran up the side of an office building, because with his "great speed he is able to overcome gravity." The question that poses itself, however, is whether he can maintain enough traction to actually run up the vertical side of the building. The act of walking or running is related to Newton's third law which states that forces come in pairs. So, when a person walks, a force must be applied to the ground with your feet, opposite to the direction they want to move. The ground hereby exerts an equal and opposite force that counters the force exerted by your feet. This parallel force is friction. For example, imagine trying to cross a floor covered with motor oil and see how many difficulties one will encounter without friction to effectively move to the other side. Therefore, without friction between his feet and the ground, the Flash would never be able to run as fast as he does.

The amount of friction opposing the motion of an object is proportional to the weight of the object pressing down on the surface. The greater the weight of the object, the greater the frictional force that must be overcome to move the object. That is the reason why it is more difficult to move a big, heavy block than a smaller, light one.

However, in the instance as the Flash runs up the vertical side of a building, none of his weight is perpendicular to the surface upon which he is running, so the side of the building. Therefore, there should be no friction between his boots and the buildings wall and without the important component of friction, he cannot run at all. That is why the Flash cannot actually run up the side of a building.

Another way he could get up the side of a building is, as he leaps up the side of the building, he moves his feet back and forth against the building's side, which would make it appear as if he were running. In essence he is traveling a distance equivalent to the height of the building in the time between steps. Typically, as the Flash runs, his foot pushes down on the ground at an angle with the road's surface so that the force the road pushes back on him is also at an angle with the surface. The effect is that he accelerates in both the vertical and horizontal direction. The vertical velocity gives him a bounce up off the ground, and the horizontal component propels him in the direction he is running.

3. Aquaman – Living Underwater

Aquaman is undoubtedly the kind of the seven seas. With his first appearance in …. It is shown that he can swim incredibly fast; he has a golden trident and can communicate with sea animals and much more. More importantly he is perfectly adapted to life in the ocean even though if a human really wanted to be able to swim in enormous depths and survive, he would have to change almost entirely.

All incarnations of Aquaman portray the character easily swimming, breathing and fighting anywhere in the ocean just as his fellow Atlanteans. According to current canon, he is still half human, meaning that he must have at least a fraction of human physiology and that his altantean genetics must have bestowed a great number of traits that makes life submerged possible. First, we will focus on the bigger problems for human that the ocean would present: ocean osmosis, body heat and nitrogen gas.

Firstly, the issue with body heat. Contrary to marine mammals like the whale of the seal, Aquaman does not possess and of the outward adaptions that allow these sea creatures to live in the extremely cold ocean. Obviously, humans have no issue swimming in the ocean as can be seen by beach vacations, but we cannot go much deeper than the surface level of the ocean without protection. The reason behind that is that even the surface level of the ocean is 10 degrees lower than the human core body temperature. After around 700 meters the temperature drops dramatically which makes only a small portion of the ocean's surface level tolerable for humans. 90% of ocean water is at or below 3 degrees Celsius and from there on the temperatures go down to 0 degrees Celsius and below 0 degrees at the poles. This is exactly where the problem lies. Aquaman is incredibly fit and has therefore a very low body fat percentage and is also nearly hairless. Consequently, he has neither fat nor fur that keeps marine mammals from freezing to death in the ocean. Standing around on the surface, one is not losing body heat that quickly but as soon as one is submerged in water one is losing body heat 24 times quicker than on the surface. Logically Aquaman would need to have a high body fat percentage or covered in a very thick an insulating layer of fur to avoid constant hypothermia. Given that he is neither, one can conclude that he might be using a more sophisticated way.

Another theory includes a complicated system inside a group of fish. In the bodies of a few very athletic fish such as tune there is a complex system of veins and arteries that is set up as a counter current heat exchange. Normally the warm blood from the care gets colder as it travels to the outside but due to the close positioning of the veins and arteries, there is a constant heat exchange as they pass by each other. This system keeps the outside of the fish colder but the inside of it warmer therefore helping to warm their internal organs and keeping them and the crucial muscles functioning at peak condition. This could be one of the solutions that Aquaman would need to swim in the depths of the ocean.

Secondly, the water itself would pose a problem to Aquaman. A human is composed mostly of water with things such as salt, ions, electrolytes, etc dissolved in it which is only separated from the outside world by a thin layer of skin. When a human loses water in the air through respiration, sweating or urination that lost water is being replaced by a liquid of a similar concentration. However, under the sea, a human body would be suddenly surrounded by water with a very different concentration. The water inside of a human body

would then be compelled due to osmosis to flow outside of the body. Osmosis is the spontaneous movement of something towards something with a higher concentration of things dissolved in it. Under the ocean, the less salty body water is forced to flow out of the body and into the ocean and therefore if Aquaman spends days or even months in the water he would start to shrivel up until his cells get smaller and his vital organs fail. Marine mammals can only regain the water that they lose to their environment from two places. Either their prey which can have a varying amount of water with salt, electrolytes, etc in them or sea water. Marine mammals lack sweat glands and so any water that they're taking back from the environment has to eventually go through their kidneys. Unlike human kidneys that filter out waste and concentrate our urine and has only one lobe per kidney, marine mammals have kidneys that have up to thousands of lobes that help their body deal with high volumes of sea water. The evolution of this organ allows them to regain water back from their environment through either the consumption of varying water with salt, electrolytes etc or sea water. For example, imagine that both a whale and a human drank 1.000 millilitres of sea water. The human would produce about 1.350 ml of urine as the concentrating capacity of a human kidney is about 400 mmol[8] while the salt capacity in water is 535 mmol. That means that the human would lose 350 ml no matter how much sea water he ingests. The whale would only produce about 650 ml of urine and therefore gain 350 ml water. The human would consequently keep losing water and dehydrate leading to death.

Thirdly, an issue that even professional drivers have to face is called the bends. The bends is an illness that comes from the rapid release of nitrogen gas from the bloodstream and is caused by bubbles forming in the blood and other tissues when one ascends to the surface of the ocean too quickly.

At ground level one is experiencing 1 atmosphere of pressure so around 7 kg is pressing on every 2.5 square cm of one's body. As water is much heavier than air, for every 10 meters of water one descends, the pressure increases 1 full atmosphere. After 30 meters below the ocean a human body would be experiencing 4 atmospheres worth of pressure and at this pressure, a human is physically incapable of inflating its lungs against the surrounding water. That is the reason as to why divers use pressurised air that matches the atmospheres of water pressure to expand their lungs. Due to this technique, divers can stay under the water for hours but always face the challenge of rising too quickly. For example, the sound that one hears after opening a soda is the gas escaping from the liquid that was dissolved in it. High-pressure gas is being put inside a liquid and then sealed into a can. That gas then comes to an equilibrium inside the can which dissolves the maximum of gas in that liquid for the temperature and pressure but when one opens the can, one changes the pressurized environment and therefore decreases the amount of the gas the liquid can hold.

Because a diver underneath the ocean has to breathe pressurised gas, more gas than normal starts to dissolve into their blood. If they were to rise too rapidly to the oceans surface, bubbles from gases such as nitrogen would then start to emerge from their blood which would result in the bends. This is extremely dangerous and can cause fatigues or headaches to seizures and death.

[8] The amount of a substance equal to a thousandth of a mole.

As seen in the comics and in the movies, Aquaman rapidly surfaces all the time which would realistically mean that the bends would have killed him already multiple times. A suggestion to solve this issue would be a swim bladder. Marine mammals swim bladders evolved to use chemistry to pump gases out of the bloodstream and fill a flexible organ that helps those animals with buoyancy and stability. If Aquaman's Atlantean genes would have given him a swim bladder that could rapidly pump out dangerous gases from his blood stream, then he would be able to ascend and descend in the ocean as quickly as he wanted.

For Aquaman to realistically be able to survive the dangers of the ocean, he would need among other things, a complex system of veins and arteries to keep him warm, kidneys that filter sea water like a whale and a swim bladder that protects him against the bends.

4. Conclusion

This memoire brought me many interesting experiences and taught me a couple of important lessons for writing research in an educational setting.

Firstly, organization is a vital component of a successful research but must be flexible. I noticed in the first months of 2022 that no matter how good the planning of the writing of my memoire was, life kept getting in the way. In the majority of cases, it was teachers who announced tests that gained priority over this research for the time being, two additional days of theatre rehearsals to my already existing four days or simply sickness. At the end of the day, I lacked the energy and motivation to continue working on this memoire which led to it being finished quite late.

I would like to point out that the quality of this work is more important than the finish date. No matter when my finish date was, as long as this work reflects the introspection and work, I put into it, I will be satisfied and even happy with it. I will keep on working on better organization skills, but I found it more mentally freeing to simply "go with the flow".

Secondly, the importance of an interesting topic and the difficulty of planning too much. At the beginning of this memoire the title was as follows "How scientifically accurate are science fiction movies?". I had planned to delve into the science but also the filmmaking behind these movies and not only explain the physics or biology of the different cases but also how they were produced with greenscreen, CGI, etc. I quickly realized that this was too big of a task and so I decided to focus on what truly interested me more, the science. After research and research on acting and movies, I wanted a new interesting variety that could still be linked back to my original interest. At the end, I realized that I was not able to fit three main chapters in the given word limit of 10.000 words. Originally planned was one chapter on the MCU, with three subchapters, one chapter on the DC Universe, again with three subchapters, and one chapter on the Star Wars Universe with either two or three subchapters. The first chapter about the MCU took about 5.000 words and that was the moment I realized that I could not include both the DC Universe and the Star Wars Universe. So, I decided on keeping the DC Universe based on the relation to the MCU. That made me change my original title to "How scientifically accurate are superhero movies?" to better accommodate the content of my memoire to my title.

Thirdly, I determined that despite the claims of superhero movies not being accurate, most of them work on being at least loosely based on our known science. Many modern superhero movies consult scientists that establish the frame of probability for their ideas and even if the movies are not aware of it, nature still has incredible ways of somehow being able to explain the abilities of superheroes such as the Spidey senses of Peter Parker. It is fascinating how a seemingly mysterious improbable stone could in theory actually work in our universe. I was particularly fond of the subchapter of the time stone as I think that space-time and the correlation between both of these matters is highly interesting.

I want to thank my friends, my family, my directrice de memoire Carole Flesh and myself for this memoire. As this is my last memoire, I hope this reflects my improvement over the years and that the readers of this memoire will see the passion, time and energy I put into this topic.

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