What is the reality behind the powers of Ant-Man in the MCU and the Marvel comics?

Superheroes cannot exist, however sad it is to admit. Not just the fact that they are fictional, but they disobey several mathematical, physical, biological and chemical rules. Take Ant-Man. He would sink through the floor every time he shrank, or rise into space every time he grew. That, or he would destroy vast parts of the planet in explosive reactions (if going by the comic description of the activity of Pym Particles).

MCU Ant-Man

The character of Ant-Man, as played by Paul Rudd, is 1.78 metres in the MCU, making him 1780mm. When shrinking to the size of an ant, he reduces his size to around 5mm. This means that his length has decreased by a scale factor of 356. Due to the relationship between linear and volumetric scale factors (**volume ∝ length**^{3}), this means that Lang's volume has decreased by a scale factor of ~4.51 x10^7, and thus his density has increased by 4.51 x10^7 times (as **density ∝ 1/volume**). The human has an average density of 1g/cm^3, and so Lang's density when ant-sized becomes 45118016 g/cm^3. For comparison, the densest naturally occurring substance on Earth is the element Osmium, at a density of ~22.6 g/cm^3. For a typical human, ~400cm^2 of the ground is in contact with their shoe, making Ant-Man have 3.156 x10^{-3} cm^2 in contact with the ground. This means his weight (using g = 9.8N/kg) of 698N is spread over 3.156 x10^{-7}m^2, and so (using Pressure = Force/Area), at this size, Lang applies a pressure of 2173522400 Pascals. This means he would sink through the Earth and burn in the core, since his pressure exceeds the compressive strength of all the substances he stands on - ~10 MPa for soil, ~175 Mpa for granite, ~300 Mpa for steel.

Thermodynamically speaking, Ant-Man would also struggle to maintain his body temperature as his surface-area-to-volume ratio will have massively increased. Maintenance of body temperature becomes mathematically impossible.

MCU Giant-Man

When growing to become Giant Man, Scott Lang would face an equally ridiculous and potentially embarrassing problem – he would become less dense than the air around him. Air has an average density of ~1.2 x10^{-3}g/cm^3. Applying the same maths as above, when at his maximum recorded height of 19.8 metres in Ant-Man and the Wasp, Lang's height has increased by a scale factor of 11.12, meaning his volume has increased by scale factor 1376. Therefore, his density has decreased by factor 1376 to 7.3 x10^{-4} g/cm^3, making him almost 2 times lighter than air, and thus he would not have been able to stride through the battlefield in the Battle of Earth in Avengers Endgame, and would rather float into the upper atmosphere, especially as he had in theory grown even bigger in that film than in Ant-Man and the Wasp (though no specific value was cited by the Marvel), and would potentially have been less dense than Hydrogen (density 8.99 $\times 10^{-5}$ g/cm^3), thus floating into space where he would die in its vacuum (though only once he started moving due to Newton's First Law of Motion).

Comic Book Ant-Man

The comic-book explanation is more mathematically plausible, at least in terms of density. In the comics, Pym Particles transfer mass to a pocket dimension called Kosmos. This therefore maintains constant density, and so Ant-Man doe not risk falling through the Earth. However, the things he is able to do if the comics are very unrealistic with that explanation of Pym Particles (not least because he has lost vast parts of his brain, his heart, his very DNA). Any-Man is seen as a fast character – at least, he travels at the same speed he would if he were his normal size. This is impossible, as he would not have the energy to do so. He has lost his enzymes, and plenty of muscle, so would not respire frequently enough to release the energy required to move at at normal human pace. If we were measuring his speed in *body lengths* per second, we would find that, rather than the normal 2-3 body lengths per second, he would travel at 356 times that (since his height has decreased by a scale factor of 356), making him travel at a rate of 712-1068 body lengths per second. This would make him faster than the fastest animal relative to size, the *Paratarsotomus macropalpis* mite, which travels at a rate of 322 body lengths per second. If Pym were travelling at this rate at human size, this would be like him travelling between 1267 and 1901 m/s, or 2851-4277 mph, which is between Mach 3.7 and Mach 5.6. He would have long since broken the sound barrier.

Thermodynamics are still under scrutiny, as surface area to volume ratio significantly increases with deceased size, no matter the mass of the person. Therefore, ant-man would still struggle to maintain body temperature, no matter the source material.

As a fun side note, when comic-accurate Ant-Man shrinks, there is a chance he would have electrical powers. Since mass is contained almost exclusively in protons and neutrons (approximately 99.9%), almost no electrons will be lost, leading to a vast increase in negative charge. This charge would attempt to leave Ant-Man's body by any means possible. There is a chance Pym could channel the electricity in a comparable way to Electro, thus becoming an electric-powered superhero.

Comic Book Giant-Man

Things become even worse when mass is added, which risks the total destruction of the planet. If Ant-Man grows, since electrons have next-to-no mass (5×10^{-4} atomic mass units), it is likely that the mass gained will be a mixture of protons and neutrons. This will lead to a charge imbalance in Ant-Man's body – doubling his mass would double the number of atoms in his body, leading to a high chance of twice as many protons as electrons. This charge imbalance would lead to electrons being ripped off of neighbouring molecules, say those in the air, leading to a violent chemical reaction as the body tries to balance its charge. Additionally, since there are more neutrons, the strong nuclear force will have increased and will outbalance the electrostatic force between protons and neutrons. This will lead to rapid nuclear decay, possibly ending with nuclear fission, and, due to the high number of atoms in a human body (as stated above), the destruction will be extreme. As Einstein stated, **$E=mc^2$**. At the stated double mass, assuming Ant-Man is normally 70kg, $E = 140\text{kg} \times (3 \times 10^8)^2 = 1.26 \times 10^{19}$ J. And that is just at double the mass (which occurs when height increases by a scale factor of 1.26, as, at constant density, **mass ∝ volume**). Ant-Man's maximum comic height is cited at around one hundred feet (30.48 metres). Hank Pym is naturally six foot in the comics (1.83 metres). Therefore, when at his maximum height, his height has increased by a scale factor of 16.67, making his volume scale factor (and thus his mass scale factor due to the constant density) 4629.63. This means that his mass has increased to ~3.24×10^5 kg. Using $E=mc^2$ again, we find that the energy he would release due to the imbalance between strong and weak nuclear forces would be 2.917×10^{22} J, which is ~3.39×10^8 times more energy than is released by 1kg of Uranium-235 in a nuclear reactor, and would most certainly be enough energy to vaporise this planet.

The energy that would be required for the synthesis of ~32300kg of body mass would be too high for him to manage – his body would eat itself up just trying. Tissue synthesis requires ~7500 kJ of energy per kg of tissue, and so he would need ~2.4×10^8 kJ of energy. The ATP would not be able to accomplish this, and, since Pym Particles are subatomic particles, and so contain next-to-no mass, not enough energy would be released from them to increase size by this much.

<u>So how ridiculous is Ant-Man?</u>

Overall, I can conclude that, despite how cool the powers of Ant-Man seem, they are mathematically and scientifically impossible in the way they are shown in both the Marvel Studios movies and in the comics. There does not appear to be any way in which one can safely increase or decrease one's size. You will either fall through the planet (and end up burning in the core), float into space, or destroy the planet with more energy than was released by both the atomic bombs that fell in Japan in 1945 combined, making the growths and reductions in size unquestionably incompatible with the natural laws of the universe. But hey, it is fiction. It is not meant to be mathematically accurate, even if the discoverer of the particles was a physicist.