

Exploring the Zoo of Matter

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Hey there, little me!

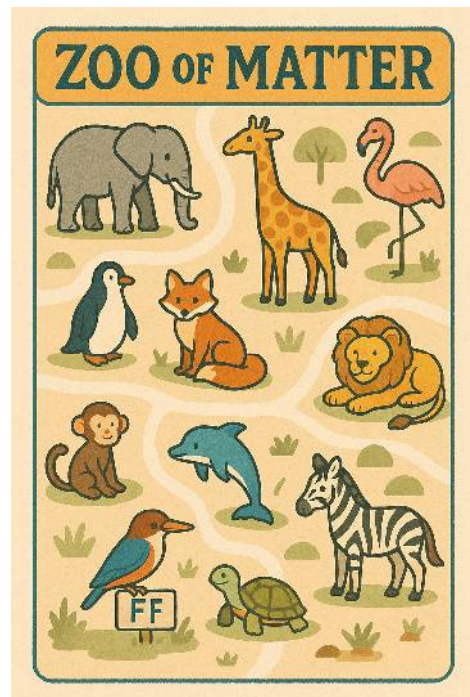
It's you, from the future. I'm now a graduate student at the University of Tokyo. Looking back to when you were 12, just beginning to ponder the universe's vast mysteries, it feels like a different world. The path from that point to where I am now wasn't always straightforward or simple, but each challenge and spark of curiosity has guided me here. I want to tell you what I'm working on, why it fascinates me, and share some insights I wish I'd known at your age.

Remember your love for figuring things out, and your fascination with space and nature? That core curiosity is still strong in me. I'm studying condensed matter physics. It sounds complicated, but it's about understanding how tiny particles like atoms and electrons team up to create everything around us: solids, liquids, magnets, superconductors, and even stranger things.

Think of it as exploring a giant, fantastic "Zoo of Material Phases." Just as a zoo has diverse animals, each unique in its behavior, material phases are similar. Water's familiar phases – ice, liquid, steam – are its common "animals." But physicists have discovered a mind-boggling variety of other, more exotic "species" that materials can become under conditions like extreme cold or pressure.

What truly hooked me is universality. This is the amazing idea that very different things in nature, seemingly unlike, can follow the same deep rules or behave in strikingly similar ways. Nature often reuses its best ideas! For instance, iron can be a magnet because countless tiny magnetic parts inside it align. When heated, these parts jumble, and it stops being magnetic. Or, think about water just about to boil. Though iron losing magnetism and water boiling are different events, the magic is, as they approach that moment of change, their behavior becomes remarkably similar. It's as if nature follows the same fundamental instructions for both at these crucial times. This means physicists like me can use similar ideas and equations to understand this behavior in many different systems, even those seeming unrelated. This shared core behavior, especially during transformations, is what I find so amazing – it reveals a beautiful, underlying simplicity in our complex world.

My little corner of this zoo involves studying "frustration-free systems." These are like unusual animals that don't follow common patterns. They have special ways of behaving, particularly at tipping points when about to change phase, showing complex collective actions. It's challenging,



but finding their secrets is incredibly rewarding. While there are established theories for many common phases, much remains unknown about these exotic systems. Even our best computers only help with small parts of the puzzle.

My little corner of this zoo involves studying "frustration-free systems." To understand them, think about the total energy of a material. This energy is the sum of countless tiny, local contributions from the interactions between neighboring particles. In most materials, there's a problem: you can't make every local interaction reach its lowest possible energy all at once. Making one group of neighbors happy (lowering their interaction energy) might make another group unhappy (raising theirs). The system must settle for a compromise, a state with built-in "frustration."

But frustration-free systems are special. They are systems where a "perfect" state can exist—one where every single local interaction throughout the material is simultaneously at its absolute minimum energy. No compromise is needed anywhere.

My research focuses on a hidden rule these systems follow when they are right at transition point (critical point). The question is: as the system gets bigger, how much slower does it get at reacting to change? This "critical slowdown" is measured by a number we call the dynamical critical exponent, z . My work prove a universal law for these systems: the value of z is always 2 or greater. This is a fundamental "speed limit" that tells us these frustration-free systems are much slower to settle down than many other materials. This isn't just a curiosity; it acts as a "no-go theorem" for computer programs that try to simulate these materials using simple, local updates. Finding these deep rules is incredibly rewarding, as it helps us understand the fundamental limits of both nature and our simulations.

If I could give my 12-year-old self advice, it would be this: Believe in yourself more. Seriously. Your curiosity and love for learning are your superpowers. You were lucky that no one actively discouraged your interests. But the biggest obstacle you'll often face is your own self-doubt. You'll look around, meet incredibly smart people, and compare yourself, thinking, "Am I good enough?" I spent too much time worrying. The truth is, while there are countless brilliant people, taking that courageous first step, daring to try something difficult, leads to growth. Everyone has a unique perspective and contributions to make. Yes, there's competition, but there's also huge space for individual exploration.

So, little me, keep feeding that curiosity. Don't be afraid to ask questions, even if they seem silly. Don't shy away from things that look hard – that's often where the most interesting discoveries lie. And trust your own abilities. You're capable of more than you think. The "zoo of matter" is vast and full of wonders, and so is your future. Keep exploring!

With all encouragement,

Your Future Self.

Acknowledgement

The language and grammar of this essay were refined with the assistance of ChatGPT and Gemini. The cover image was created using ChatGPT.