Low Temperature Physics: One of the Most Attractive Stage of Extreme Environment

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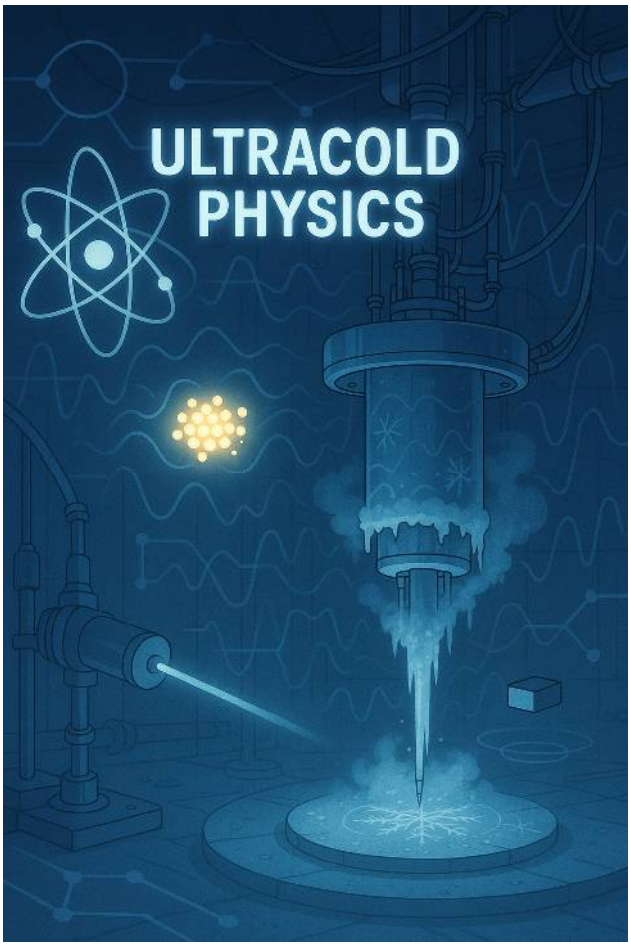

When you hear the term “low temperature,” how low do you imagine it is? The temperature in the refrigerator, or below the melting point of water? If you have fun with “Pokémon”, you may have heard of “Absolute Zero”, which can bring your opponent fainting. In physics, there is a lower limit of temperature where everything can reach. This is called “Absolute Zero”, and it is -273.15 ℃.

Now, I am working on ultralow temperature measurement, which can reach the temperature only 0.02 degree higher than absolute zero. At such low temperature, a lot of strange phenomena occur. Especially, I am carrying out an experiment of superconductivity. This is the phenomenon which can transport electric current without loss of energy. You may have an experience of your smartphone overheating, and this is because electric current is always generating heat. However, in the

superconducting state, it does not generate heat at all. This nature has a potential to be applied to industry, such as maglev trains or medical devices.

Then, how can we identify that the material is in the superconducting state? The answer is measuring how the properties of the material change when the temperature changes. For example, heat capacity, or how much energy we need to warm the material by 1 degree, is a good probe of the state of the material. As you may know, an iron pan heats up more easily than water. This means that the heat capacity of an iron pan is smaller than that of water. As we gradually lower the temperature of the material, sometimes the heat capacity changes discontinuously, and this is the point where the state of the material changes. By finding this kind of point, we can recognize the superconducting state. To apply this phenomenon to industry, it is important to think of the superconducting material which can be easily obtained and is not so expensive.

I find low temperature physics interesting because the “extreme environment” is quite fascinating for me. Now, we are living in the “normal environment”, which means normal temperature, normal pressure, and so on. Certainly, interesting phenomena can happen in the normal environment, and these phenomena are important for us to utilize. However, the phenomena in the extreme environment are more attractive for me. We cannot directly experience those phenomena, so measuring in that environment is like jumping into a whole new world!

Then, why is low temperature interesting for me rather than other extreme environment, such as high pressure? This is because at low temperature, the nature of quantum mechanics becomes very evident. Every material is composed of atoms, and quantum mechanics can describe the world of them. An atom has electrons, whose flow is called electric current, and they are also described by quantum mechanics. It seems that nothing can vibrate (or everything is completely “frozen”) at absolutely zero, but quantum mechanics tells us that everything has a certain vibration there. This

results in a certain amount energy, which is the lowest energy the material can have. The state having the lowest energy is called ground state, and searching for the ground state is essential to investigate the “quantum nature” of the material, described only by quantum mechanics.

How does quantum nature emerge? For example, the nature of a magnet is the most familiar quantum nature. If the temperature of a magnet becomes very high, it is no longer a magnet. This means that the quantum nature has completely vanished. In the measurement of heat capacity, quantum nature emerges clearly. For almost all metals, when the temperature changes, the heat capacity does not change so much at normal temperature, but it changes drastically at low temperature. This is caused by the quantum nature of electrons and the “lattice” (which is like a home where electrons live). When I first learned this as an undergraduate student, I found this very attractive because a familiar-sized material exhibits a quantum phenomenon. Therefore, in terms of the quantum nature, low temperature is the most fascinating extreme environment to me.

Here, I have some advice to my 12-year-old self. First, you should pay attention to not only quantitative nature of physical phenomena, but also qualitative nature of them. You will take lectures of physics in junior high school and high school, and you will learn many equations which can describe the physical phenomena. Of course, they are very important, because your future research will be largely based on them. The results of the experiment are usually quantitative, so the importance of quantitative nature is needless to say. However, understanding qualitative nature is also essential for you to do the real experiment. As for the low temperature measurement, it involves a lot of complicated procedures, such as how to handle the gas system and how to transform gas into liquid. These procedures require you to understand how gas or liquid behaves, so qualitative understanding is much more helpful when you are doing the experiment. The real experiment usually has a time limitation which does not allow us to ponder what will happen, and we need an instant answer. Understanding qualitative nature will help you to come up with the instant answer!

Second, you should be interested in chemistry, which describes the properties of individual materials. Your future major is physics, whose goal is said to find a universal rule of the natural world. Then, individual properties seem to be trivial for physicists. However, especially in the field of material science, individual properties are quite important. We cannot observe interesting phenomena of materials until we investigate the properties of individual materials. Furthermore, a lot of chemicals help us do the experiment. We use organic matters when we synthesize and polish the material to be measured. Understanding the properties of Helium is necessary when we do the low temperature measurement. Therefore, chemistry is also important for material physics.

It's great that you will become interested in physics, but if you expand your interest a little, the world will look different.

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