Meanwhile, in Munich, Germany…

Remember when I said that absolute zero is "traditionally" believed to be the lowest possible temperature? Well, this temperature limit may not actually be true according to recent experiments in the Ludwig Maximilian University in Munich, Germany and the Max Planck Institute of Quantum Optics in Garching. Using lasers and magnetic fields, physicists Ulrich Schneider and Immanuel Bloch have actually achieved temperatures below absolute zero!

But what do negative values on the Kelvin scale actually mean? Definitely not what anyone would expect: atoms at these negative temperatures are not cold. They are actually extremely hot!

To understand why this makes sense, consider what is called the "Boltzmann distribution." Even though a gas might be at a certain fixed temperature, the individual gas particles will all have different amounts of kinetic energy (remember this means that they will be moving at different speeds). According to the Boltzmann distribution, most molecules will have lower or average energies, while only a few will move very quickly. When the Boltzmann distribution is reversed (the majority of the molecules have higher energies, and only a few are moving slowly), the temperature is negative. Since the majority of the molecules are moving very quickly, they have a large amount of energy, and the gas is extremely hot rather than extremely cold.

So, the traditional belief that temperatures colder than (and equal to) absolute zero are unattainable is probably true! When cooling atoms to extremely low temperatures, they jump from just above absolute zero (very cold) to just below (very hot), but they are never completely motionless.

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Physics Brochures Series by Sarah Marie Bruno, '16
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Ultra-cold materials…

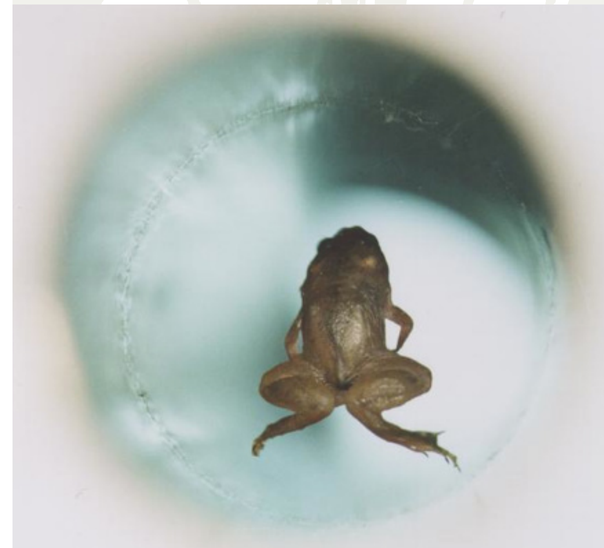


Image by Lijnis Nelemans, High Field Magnet Laboratory, Radboud University Nijmegen.

…and levitating frogs!

HELPING TO FURTHER

PUBLIC UNDERSTANDING

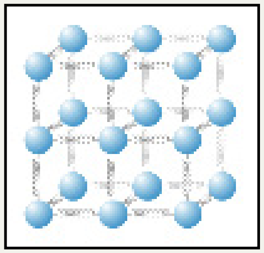
OF PHYSICS CONCEPTS

Absolute Zero!

Zero degrees Fahrenheit is pretty cold right? Well, what about zero degrees Kelvin? Kelvin (K) is another scale for measuring temperature, like Celsius (C) or Fahrenheit (F), but zero degrees Kelvin is equal to -273.15º C and -459.67º F! That's pretty cold! This temperature is called "absolute zero," because it is traditionally believed to be the coldest possible temperature. Physicists working with ultra-cold atoms can cool materials down to temperatures near 0 K, but cannot actually achieve absolute zero itself.

Why might absolute zero be unattainable? Have you ever wondered what makes the air feel hot or cold? Temperature is really a measure of how fast particles are moving or how much kinetic energy they have. ("Kinetic energy" refers to the energy of an object in motion. For example, if a ball is moving very fast, it has a large amount of kinetic energy.) When it is hot outside, the air particles have a lot of energy, so they are flying around quickly. On the other hand, the air particles are moving slowly when it is cold out.

Theoretically, if molecules were to stop moving altogether, the temperature would be absolute zero. Therefore, absolute zero can be thought of as the complete absence of motion. (It is interesting to note that since sound waves require motion, a world at absolute zero would be completely silent!) This state of motionlessness is probably impossible, because particles are always moving. Even the molecules that make up solid objects such as your desk and your textbook are constantly vibrating in place—they just vibrate so quickly and so slightly that we do not notice it!



You can visualize a solid as a lattice of molecules linked together by little springs that allow the molecules to vibrate in place.

As scientists explored the frontiers of colder and colder temperatures, they discovered some very interesting properties of certain materials when cooled to extremely low temperatures. You probably know that electricity works due to the electric current (moving electric charges) in metal wires. A lot of power is lost when this current flows from one place to another, however, due to the "resistance" in the wires. Resistance, as the name suggests, resists the flow of current, causing energy to be lost as heat. Something amazing happens, though, when certain metals are cooled to very low temperatures… they lose their resistance! Lead, for example, has no resistance at temperatures below 7.2 K, Tin below 3.7 K, and Aluminum below 1.2 K. Current would continue to flow in these materials at these low temperatures, even without a power source such as a battery connected to them. That is why they are called "superconductors."

Unfortunately, it is still too impractical to use superconductivity to conserve electrical power in homes, but the property is used for what is called "magnetic levitation." You are probably very familiar with magnets and have observed that the north pole of one magnet repels the south pole of another magnet. But did you know that an electric current can cause, or induce, a magnetic field? A loop of current in a superconducting disk, for example, can act as a magnet, repelling (pushing away) other magnets that then hover above the disk, suspended in the air!

A superconductor levitating a magnet; the misty vapors are caused by the very cold liquid nitrogen used to cool the superconductor. (Photo: Rikare Liv).

Because there is no resistance in the superconductor, this current, and therefore the magnetic field, will continue as long as the disk is kept at a low temperature. Here's something that may surprise you: some materials not normally considered to be "magnetic" can become temporarily magnetized if they are placed near a super-strong magnet. This strange property is called "diamagnetism." Water, for instance, is a diamagnet, which means that anything with a lot of water in it, such as a frog, is diamagnetic as well. Yes, this means you can levitate a frog above a superconductor!

Unfortunately, there is not a huge market in our world for levitating frogs, but magnetic levitation is used to operate the high-speed trains in Japan, China, and parts of Europe. You may have heard these trains referred to as "maglev trains." You guessed it—"maglev" is short for magnetic levitation! These incredibly fast trains can travel up to 320 km/h! That is almost 200 miles per hour!

A maglev train whooshes by! (Photo: Alex Needham).

These trains can move so quickly, because they are actually levitated above the track. When steel wheels roll on a train track, the wheels and the track scrape against each other, allowing energy to be lost, slowing down the train. This scraping force is called "friction." Magnetic levitation eliminates this problem, so that trains can zip along at high speeds, guided by the track. This allows for much faster, more efficient transportation!