Misconceptions in Thermodynamics

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Abstract

Persistent misconceptions in thermodynamics continue to obscure fundamental understanding, particularly in areas such as temperature, phase transitions, thermal expansion, absolute zero, Brownian motion, the rotation of Crookes radiometers, and even the second law of thermodynamics. A prevalent misunderstanding is the notion that temperature represents the average kinetic energy of particle motion. As one of the seven fundamental physical quantities, temperature plays a crucial role in a wide range of physical phenomena. Misconceptions about its nature have led to confusion in domains well beyond those listed above, extending to concepts like electrical resistance, superconductivity, and even superfluidity. For example, the classical kinetic theory of gases, based on this flawed interpretation of temperature, consistently underestimates the specific heat of polyatomic gases compared to experimental observations, a discrepancy that has sparked scientific debate for centuries. This article synthesizes insights from a wide range of research to develop a unified framework for more accurately understanding these foundational concepts, thereby addressing longstanding ambiguities in thermodynamics and related fields.

Introduction

Certain misconceptions in thermodynamics have become deeply ingrained, often presented as common knowledge in educational materials and textbooks. For instance, temperature, one of the seven fundamental physical quantities, is commonly described as a measure of the average kinetic energy of particle motion in a system. Thermal expansion is frequently attributed to increased molecular vibrations at higher temperatures, implying that atoms or molecules require more space due to more vigorous motion. Similarly, phase transitions are often explained as a consequence of intensified molecular vibrations leading to bond disruption. Brownian motion is typically attributed to collisions resulting from random molecular movement. However, studies suggest that these widely accepted explanations are, in fact, misconceptions.

These fundamental concepts are so deeply embedded in scientific thought that they may have distorted our interpretation of observations or led to incorrect understandings, thereby impeding theoretical and technological progress. For example, electrical resistance is commonly attributed to collisions between electrons and other particles within a conductor, particularly at elevated temperatures. To account for superconductivity, a phenomenon characterized by zero electrical resistance, the Bardeen-Cooper-Schrieffer (BCS) theory posits that electrons form Cooper pairs.[1] These pairs, bound by electron-phonon interactions, are believed to move through the lattice without scattering, thereby eliminating resistance. Electron-phonon interactions are generally believed to play a significant role in superconductivity only at low temperatures, typically below 40 K, since increased thermal vibrations of electrons and the crystal lattice at higher temperatures are thought to weaken these interactions, thereby disrupting Cooper pair formation and leading to the breakdown of superconductivity.

However, this theory faces growing challenges with the discovery of high-temperature superconductors, many of which require extremely high pressures to exhibit superconductivity. Since 1986, a variety of materials have been found to exhibit superconducting behavior at temperatures far exceeding the theoretical limit predicted by BCS theory.[2–6] The current record holder is lanthanum decahydride, which has a superconducting transition temperature of 250 K under high pressure.[7] Moreover, while high pressure appears to enhance superconductivity in these materials, BCS theory does not account for the positive effect of pressure, leaving a significant gap in our theoretical understanding.

Despite over a century of research since the discovery of the first superconductor, a practically viable room-temperature superconductor remains unrealized. Although the BCS theory has been instrumental in guiding the development of superconductivity research, it is built upon assumptions that may arise from deeper conceptual misunderstandings. The conventional explanation of electrical resistance attributes it to collisions between electrons and the crystal lattice—a view rooted in the concept of molecular vibrations. Yet this perspective ultimately derives from more fundamental misconceptions about the nature of temperature. These flawed foundations may have misdirected scientific efforts in the wrong direction, hindering both theoretical advancements and technological innovations.

This may be just one example of the critical role that fundamental concepts play in shaping scientific understanding and technological development. This article summarizes efforts across various studies aimed at correcting foundational misconceptions and misunderstandings. The new insights emerging from this work offer a more accurate perspective on these issues, paving the way for future advancements in both theory and application.

Limits of the Kinetic Theory of Gases

If the temperature of a system represents the average kinetic energy of particle motion, changes in temperature and kinetic energy could be used to predict the specific heat of the system using the kinetic theory of gases. The average kinetic energy due to the motion of a single molecule in an ideal gas can be derived from the kinetic theory as follows:[8-11]

$$(1) \qquad K = \frac{3}{2}k_B T$$

Here, T is the absolute temperature of the system, and k_B represents the Boltzmann constant. Specific heat capacity is the energy required to raise the temperature of a unit mass of a given substance by one degree. Accordingly, the molar-specific heat capacity of ideal gases can be predicted in the kinetic theory using the following expression:

$$(2) \qquad C_m = \frac{KN_A}{T} = \frac{\frac{3}{2}k_B TN_A}{T} = \frac{3}{2}R$$

Here, C_m represents the molar-specific heat capacity predicted in the kinetic theory, N_A denotes Avogadro's number, and R is the molar gas constant. These theoretical values can be directly compared with experimental data. For gases composed of monatomic molecules, the predictions of the kinetic theory closely match experimental data, regardless of atomic mass, with an accuracy of approximately 99%. In contrast, the theory fails to accurately predict the specific heat of gases composed of polyatomic molecules. The predicted values are consistently lower than the measured ones, and the discrepancy increases with molecular complexity. For example, the predicted specific heat for octane accounts for only 7% of the measured value, indicating a 93% error.

To resolve the discrepancies in the kinetic theory, additional components were incorporated into the kinetic energy model: translational energy for particle motion, vibrational energy for particle vibrations, and rotational energy for particle rotation. Maxwell proposed the equipartition of energy among these three modes,[12] effectively multiplying the predicted energy by a factor of three. However, even with this scaling, the model still fails to account for the discrepancies. Boltzmann refined the equipartition principle by introducing the concept of degrees of freedom, proposing that energy in a gas is equally distributed among all accessible degrees of freedom.[13-14] Each additional atom in a gas molecule increases from three up to seven degrees of freedom, depending on the complexity of the molecules. Consequently, the predicted specific heat is further scaled up according to the number of atoms within each molecule. To reconcile the model with experimental results, various modifications have been proposed subsequently.[15-16]

This problem has remained a longstanding puzzle in the field of thermodynamics for centuries. To understand the inconsistency, numerous explanations have been proposed to account for the failure of the equipartition principle. Boltzmann suggested that gases might not be in thermal equilibrium.[17] Planck and Einstein introduced the idea of a zero-point harmonic oscillator to explain the discrepancy.[18-19] Kelvin eventually concluded that the equipartition assumption might be incorrect,[20-21] a view later acknowledged by Einstein.[22-23]

Can Temperature Represent Kinetic Energy?

If temperature were solely a measure of kinetic energy, then by definition, specific heat should arise exclusively from changes in kinetic energy. Under this assumption, gases, owing to their substantially greater molecular freedom, would be expected to exhibit higher specific heat capacities than liquids. However, empirical observations contradict this expectation: most substances exhibit higher specific heat in the liquid phase. For instance, the specific heat of liquid water is nearly three times that of steam. This discrepancy, along with the long-standing mismatch between experimentally measured values and predictions made by kinetic theory, challenges the assumption that temperature is purely a manifestation of kinetic energy. Could this foundational premise be fundamentally flawed?

A common factor underlying both discrepancies is the presence of additional bonds. In liquid water, the higher specific heat is associated with the formation of extensive intermolecular hydrogen bonds. Similarly, the deviation between experimentally measured specific heats and those predicted by kinetic theory arises primarily in polyatomic gases, where multiple intramolecular bonds exist between atoms. These observations suggest that bonding, both intermolecular and intramolecular, plays a significant role in heat capacity, beyond what is accounted for by kinetic energy alone.

Potential energy naturally arises from interactions between particles, such as the electrostatic forces between electrons and nuclei. It is well established that chemical bonds store energy, typically quantified as enthalpy. Likewise, intermolecular and intramolecular bonds can serve as reservoirs of energy. Much like springs, these bonds store energy when stretched. As work is done to increase the distance between bonded atoms or molecules, that energy is retained as potential energy within the bonds.

This understanding aligns with observed patterns in specific heat behavior: the kinetic theory accurately predicts specific heat for gases composed of simple molecules without internal bonds, while discrepancies between predicted and measured values increase with the presence of molecular bonds. This trend becomes especially evident when comparing molar-specific heat values to the corresponding number of chemical bonds in gas molecules. To illustrate this relationship, Figure 1 presents the correlation between molar-specific heat and the number of bonds for a set of gases.[24]

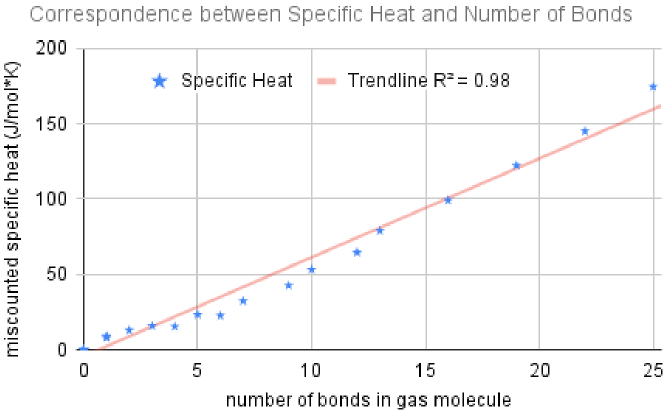

Figure 1: Correlation between molar specific heat and the number of molecular bonds in gas molecules. Each point represents one type of gas. The “miscounted” molar-specific heat refers to the difference between the experimentally measured values and those predicted by kinetic theory. The fitted trendline demonstrates a strong linear correlation, with a coefficient of determination R² as high as 0.98.

The following key implications emerge from these observations. The specific heat added to a system is primarily distributed between kinetic and potential energy. The portion predicted by kinetic theory corresponds to the kinetic energy contribution and remains accurate across different single-atom gases, regardless of molecular mass or complexity. This suggests that equipartition-based adjustments to kinetic theory may be unnecessary. The remaining energy is primarily allocated to increasing the potential energy stored in molecular bonds, and this portion increases with the number of bonds.

Consequently, temperature cannot be fully represented by kinetic energy alone, as a substantial part of the specific heat is associated with potential energy changes. A small fraction of the energy may also contribute to elevated radiation levels or the excitation of electrons to higher average orbitals; however, this contribution is negligible within the limits of experimental measurement accuracy.

The Connection between Temperature and Potential Energy

The preceding observations seriously challenge the traditional association between temperature and kinetic energy. This raises a critical question: Does temperature more directly represent a system’s potential energy? However, in practical applications, many thermometers, particularly infrared thermometers, do not measure kinetic or potential energy directly. Instead, they detect radiative energy, without requiring direct contact with the target.

The behavior of ideal radiative emission is described by Planck’s law, which defines the spectral distribution of radiation as a function of wavelength and temperature.[25-27] Planck’s law infers that the total radiative power P emitted by a perfect blackbody is proportional to the fourth power of absolute temperature, as expressed by the Stefan–Boltzmann law:[28–29] By reorganizing their equation, the temperature can be expressed in terms of the emission power of a target system:

$$(3) \qquad T = \sqrt[4]{\frac{P}{p}}$$

Here, p is the Stefan-Boltzmann constant. This relationship indicates that temperature can be determined from the radiation emitted by a system, forming the theoretical basis for temperature measurement devices. Another direct consequence of Planck's radiation law is Wien's displacement law, which states that the peak wavelength of emitted radiation shifts inversely with temperature:

$$T = \frac{b}{\lambda} \tag{4}$$

Here, λ represents the peak wavelength of the radiation curve, and b is Wien's displacement constant. This relationship allows temperature to be determined by measuring the peak wavelength of radiation emitted by a system. For instance, an experienced baker can tell oven temperature by observing the color of the flame. Similarly, the Sun's surface temperature can be determined from its peak emission near 500 nm, corresponding to approximately 5,778 K. These examples illustrate how temperature is fundamentally linked to the radiative energy emitted by a source.

Radiation is closely connected to changes in a system's potential energy. For example, an accelerating charged particle, such as an electron, transitioning between atomic orbitals, emits energy in the form of radiation. Conversely, when radiation is absorbed, an electron may become excited to a higher orbital, with the absorbed energy stored as potential energy. Intermolecular and intramolecular bonds similarly absorb or emit radiation through changes in their potential energy. For instance, thermal energy is released or absorbed during chemical reactions as intramolecular bonds are broken or formed. Likewise, during phase transitions, changes in intermolecular bonds lead to the absorption or release of latent heat.

Essentially, radiative energy originates from the transformation of potential energy stored in bonds or orbital electrons, underscoring the intrinsic connection between these energy forms. This perspective helps explain the observed correlation between the specific heat and the number of bonds in gas molecules, as shown in Figure 1. Consequently, temperature is linked to potential energy through the radiative processes of a system's potential components. As a result, temperature is more closely associated with a system's radiation level and potential energy than with its kinetic energy.

The Origin of Kinetic Energy of Particle Motion

What role does kinetic energy play within a system, and how does it originate? These questions are examined through a process known as *transimpact*.[30] Electrostatic attraction typically acts between nearby atoms or molecules; however, when they come too close, electron-electron repulsion increases sharply. A stable equilibrium is established at a characteristic distance, where these opposing forces balance. This equilibrium can be disrupted during atomic electron transitions. When an electron absorbs energy, it becomes excited to a higher orbital, typically within a few nanoseconds or less.[31-32] As the electron cloud expands, the volume of the host atom increases, reducing the distance to adjacent atoms. This abrupt decrease in spacing disrupts the electrostatic balance, often triggering a sudden increase in repulsive forces that push atoms apart. This dynamic process, illustrated in Figure 2, is referred to as *transimpact*.

Transimpacts are explosive, impulsive events, much like the sudden burst of popcorn, that forcefully propel adjacent particles apart, imparting significant momentum and initiating or amplifying their motion. These events are driven by atomic electron transitions, which occur routinely at the microscopic scale. As such, transimpacts represent pervasive interactions that play a fundamental role in many physical processes, particularly within thermodynamics. Ultimately, the kinetic energy of microscopic particles originates from radiative energy and reflects underlying changes in potential energy.

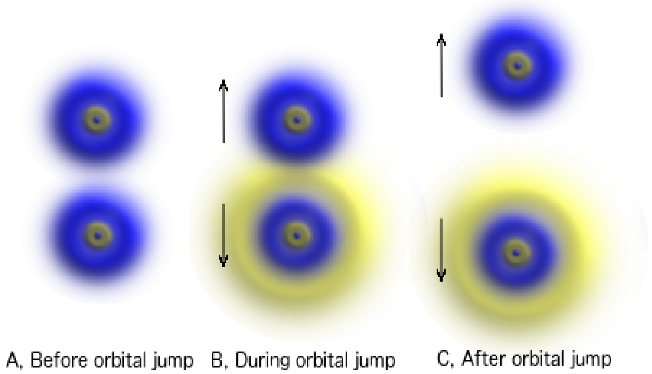

Figure 2: Transimpact due to an atomic electron transition.

Transforming Kinetic Energy into Potential and Radiative Energy

While transimpacts facilitate the buildup of kinetic energy within a system, this accumulation cannot continue indefinitely. A complementary mechanism must exist to convert kinetic energy into other forms—a process known as *impactrans*.[30] In impactranses, the motion or vibration of particles (such as molecules, atoms, or subatomic particles) leads to collisions via electrostatic interactions. These interactions can excite electrons to higher orbitals or even eject them entirely, thereby altering their potential energy. Additionally, the accelerated motion of electrons during such impacts can result in the emission of radiation. Through impactranses, kinetic energy is transformed into both potential and radiative energy, helping to maintain a dynamic energy equilibrium within the system.

The conversion of kinetic energy into radiative and potential energy through impactranses is evident in many everyday phenomena. A common example is the dent formed on a surface after being struck by a hammer. The deformation arises from alterations in the bond structure. Some bonds are compressed, others are stretched, absorbing the hammer's kinetic energy as potential energy. Some change in the potential energy of the impacted bonds is released as radiative heat, a process commonly experienced as impact heat, which frequently occurs during collisions. At its core, this impact can be understood as a collective impactrans process involving a vast number of particles.

For another example, the warmth experienced when rubbing one's palms together results from frictional heating—an effect of impactranses, where kinetic energy from surface motion is transferred to particle-level interactions on rough surfaces. A similar mechanism explains the heat generated at the base of a pump tube, where intensified molecular collisions increase the frequency of impactrans events. In the case of static electricity, rubbing a plastic rod with fur dislodges electrons from atoms, resulting in the accumulation of electric charge—another clear manifestation of impactranses at work.

Together, transimpact and impactrans facilitate the transformation of kinetic energy to and from potential and radiative energy. Heat is commonly transferred through conduction, radiation, and convection. While radiation transfers energy and convection moves both energy and matter through space, the underlying mechanism of conduction remains less clearly understood. The concepts of transimpact and impactrans offer a compelling framework to explain conductive heat transfer, helping to bridge a longstanding gap in our understanding of this fundamental process.

Temperature Reflecting Dynamic Energy

Thermal energy, commonly referred to as heat energy, is traditionally defined as the total kinetic energy of a substance's particles, including their translational, rotational, and vibrational motion. Temperature is typically regarded as a measure of this thermal energy, specifically, an indicator of the average kinetic energy of the particles within a system. However, the preceding observations suggest that these conventional definitions may be inaccurate or fundamentally flawed, as they overlook substantial contributions from potential energy and radiative processes.

In reality, potential energy, radiative energy, and kinetic energy are not distinct or isolated forms; rather, they continuously transform into one another. Radiative and potential energy are exchanged through atomic electron transitions. Transimpacts convert radiative energy into kinetic energy, while impactranses transform kinetic energy into both potential and radiative energy. Together, these forms constitute the dynamic component of a system's internal energy. Although all three influence temperature, it is most directly determined by radiative energy, which originates from potential energy. Kinetic energy contributes indirectly, as it tends to correlate positively with both radiative and potential energy. To capture this interrelationship, the term *dynamic energy* is defined as the sum of these three interdependent components:[33]

$$T = R + U + K \qquad (5)$$

Here, T denotes a system's dynamic energy, including radiative energy R, potential energy U, and kinetic energy K. The continuous transformation among these forms drives the system's evolution over time. By grouping them collectively as dynamic energy, it highlights their inherently interactive and ever-changing nature. This conceptual framework offers both a foundational perspective and an underlying mechanism for understanding thermodynamics.

Temperature reflects the radiation level of a system and is closely associated with its potential energy, which serves as the primary source of emitted radiation. Through ongoing processes such as transimpacts and impactranses, kinetic energy continuously exchanges with radiative and potential energy, establishing an indirect connection to temperature. In this framework, temperature functions as an indicator of a system's overall dynamic energy level.

Misconceptions in Thermal Expansion

Classical textbooks often mistakenly attribute thermal expansion to increased molecular vibrations, suggesting that as the temperature rises, particles vibrate more vigorously and thus require more space. If vibration alone causes expansion, a substance's volume should increase monotonically with temperature, since vibrational intensity generally grows with heat. However, this explanation fails to account for thermal contraction, such as water, which contracts as the temperature rises above 0 °C and reaches maximum density at 4 °C before expanding again. Such behavior directly contradicts the predictions of the vibration-based model and exposes fundamental flaws in its underlying assumptions.

Thermal expansion is fundamentally linked to changes in molecular bond structure.[34] To accommodate the added energy, intramolecular and intermolecular bonds stretch, increasing the volume and contributing to the expansion of materials. Thermal expansion manifests through changes in bond structure in two key ways: in crystalline solids, expansion can vary by direction due to the anisotropy of the crystal lattice, and the volumetric thermal expansion coefficient generally correlates with molecular complexity, as more intricate structures tend to allow greater bond flexibility and energy absorption.

Importantly, a substance’s volume is influenced not only by bond lengths but also by the overall structure of its bonding network. This distinction helps explain anomalous behaviors like thermal contraction in systems where bonding leads to more compact arrangements, such as the hydrogen bonding in water near 4 °C. Hydrogen bonds create intermolecular attractions between water molecules. As temperature decreases, these bonds become shorter and stronger, drawing molecules closer together and reducing volume, demonstrating normal thermal behavior. However, around 4 °C, the hydrogen bonds are strong enough to form a scaffold-like network that locks water molecules into fixed positions, creating hollow, less-dense structures similar to those found in snowflakes. As the temperature continues to fall, this crystalline arrangement becomes more pronounced, leading to expansion even as the system’s temperature declines. Although traditional thermal expansion from bond lengthening still occurs, its effect is outweighed by the structural changes driven by hydrogen bonding at lower temperatures.

Thermal expansion fundamentally arises from changes in bond structures, which themselves originate from interparticle forces. It is essential to recognize that attractive forces between particles are not limited to chemical bonds between atoms or molecules, but also include electrostatic attractions between electrons and their host nuclei. As a result, even monatomic substances, despite lacking molecular bonds, exhibit thermal expansion, typically isotropic due to their symmetric atomic arrangements. In contrast, materials with complex or anisotropic bonding networks, such as crystalline solids, often display asymmetric thermal expansion or contraction. These directional variations cannot be adequately accounted for by conventional vibration-based models, underscoring the need for a more comprehensive framework centered on the dynamics of bonding interactions.

The Cause of Phase Transition

Another common misconception is that phase transitions are driven primarily by the increasing intensity of molecular vibrations at elevated temperatures. In truth, molecular vibrations result from transimpacts, not the other way around. Transimpacts are more energetic and fundamental than vibrations, as they are the means through which vibrational energy is transmitted. In most cases, bonds are broken by transimpacts before vibrational energy can reach a level sufficient to cause structural change. Phase transitions are best understood as the outcome of an interplay among three key forces: external pressure, the bond forces that maintain molecular cohesion, and transimpacts that act to disrupt those bonds.[35]

At lower temperatures, transimpact forces T are weaker than the combined retaining forces of intermolecular bonds B and external pressure P, allowing the system to maintain structural integrity. As the temperature rises, the average intensity of transimpacts increases, while bond strength generally decreases due to expanding intermolecular distances driven by elevated dynamic energy. Eventually, a critical temperature is reached at which the transimpact force becomes sufficient to counteract and exceed the combined retaining forces ($B + P$), leading to a phase transition, which can be represented by the equilibrium condition among the three forces:

$$T(t, d) = B(d) + P \tag{6}$$

This defines a strength limit of bonds for a given state of matter. As more energy is introduced into the system, the intermolecular bonds can no longer restrain the molecules against the rising intensity of transimpacts. A phase transition occurs when these bonds are broken, liberating the molecules from their fixed positions. During this transition, latent heat is absorbed, not to raise temperature, but to break the bonds and increase the kinetic energy of the now-freed molecules.

A similar balance to that described in Equation 6 occurs during gas-to-plasma transitions. In this case, the dominant bonding force becomes the electrostatic attraction between electrons and their nuclei, while the transimpacts are replaced by atomic electron transitions. Here, the transition involves the ionization of atoms as electrons are stripped away.

It is important to note that Equation 6 represents a balance between the retaining forces (such as pressure and bonding) and the disrupting force of transimpacts. This balance is typically achieved as bonds weaken at elevated temperatures. However, individual transimpacts of exceptionally high intensity can overcome even relatively strong bonds at lower temperatures, ejecting molecules from the surface and resulting in phenomena such as sublimation or evaporation. A similar mechanism applies to the photoelectric effect,[36] in which high-energy photons eject electrons from a material, even at low temperatures, without triggering a plasma phase transition. Accordingly, these transitions can be classified as either bond-limited or impact-driven, as summarized in Table 1.

	Solid to Liquid	Liquid to Gas	Gas to Plasma
Bond-Limited Transition (High Temperature)	Melting	Boiling	Ionization
Impact-Driven Transition (Low Temperature)	Sublimation	Evaporation	Photoelectric Effect

Table 1: Comparison between bond-limited and impact-driven transitions

In other words, bond-limited transitions are standard phase changes that occur at high, and typically well-defined, temperatures, when bonds are stretched to their maximum extent and can no longer retain structural cohesion. In contrast, impact-driven transitions result from exceptionally high-intensity transimpacts that overcome relatively strong bonding forces, typically at temperatures below the normal phase transition point.

Phase Transition at Constant Temperature

Traditional textbook explanations assert that the latent heat supplied during a phase transition is entirely consumed in breaking intermolecular bonds, resulting in no net increase in particle kinetic energy and, therefore, no change in temperature. However, this reasoning rests on the implicit assumption that temperature directly reflects the average kinetic energy of particles—a view that, as this study suggests, may be fundamentally flawed.

During a phase transition, such as the melting of ice into water, molecules are released from their fixed positions within the hydrogen-bond network, leading to increased mobility. As these molecules are expelled from the structured network, their kinetic energy must also rise. If temperature truly reflected the average kinetic energy of the system, it would be expected to increase during the transition. So why does the temperature remain constant?

In light of the insights presented thus far, the apparent paradox becomes more comprehensible. As energy is introduced into a system, electrons are excited to higher orbitals, causing atoms to move farther apart and thereby stretching and weakening intermolecular bonds. Simultaneously, the temperature rises, reflecting the increased radiation emitted by these increasingly strained bonds. In parallel, the system's kinetic energy increases, driven by the intensifying transimpacts.

The temperature remains constant during a phase transition primarily because the extension of intermolecular bonds reaches its limit, resulting in an anchor effect. [35] As energy is added, these bonds stretch and accumulate potential energy, gradually weakening in strength. Eventually, they can no longer withstand the increasing intensity of transimpacts and begin to break, signaling the onset of the phase transition. At this stage, the system's potential energy plateaus, and the radiation level emitted by the strained bonds stabilizes. Since temperature reflects this radiation level, it remains constant throughout the transition.

During a phase transition, latent heat is used both to break molecular bonds and to increase the kinetic energy of the liberated molecules. Consequently, the kinetic energy of particles does indeed rise during the transition, contrary to the common assumption that it remains unchanged. However, these kinetic changes do not affect the system's radiative emission and therefore are not reflected in temperature. Similarly, the breaking of bonds does not alter emission levels; only changes in the potential energy components, specifically, the bonds themselves, influence radiation. Because the system's emission is limited by the maximum potential energy reached during the transition, the temperature, which reflects this radiative level, remains effectively constant.

Variable Temperature Phase Transition

However, not all phase transitions occur at a constant temperature. For a transition to proceed isothermally, the energy required to alter intermolecular bonds must compete with the energy that would otherwise change the system's temperature. For instance, when ice melts into water, added energy is used both to break intermolecular bonds and to raise the temperature. These competing demands prevent simultaneous temperature change during the transition. In contrast, during the superfluid transition of helium, energy is extracted to lower the temperature while simultaneously being consumed to break the interactions between helium atoms. Since these two processes do not compete for the same energy, the transition does not occur at a fixed temperature. Instead, the temperature decreases throughout the transition, spanning from just above 2.6 K down to 2.17 K.[37]

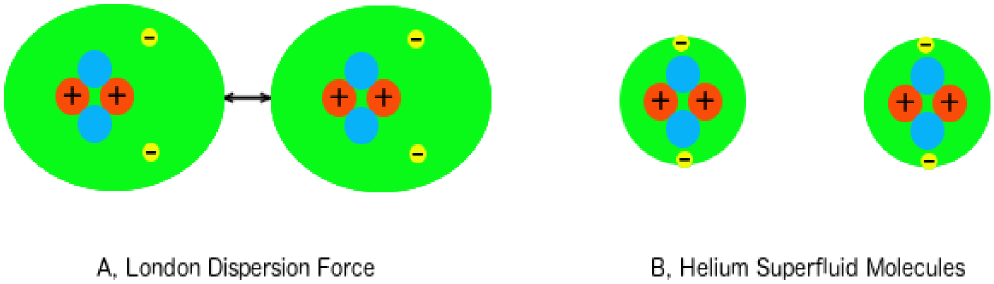

Figure 3: Superfluid—a collection of particles without attraction. A) Bonds are formed between helium molecules at high temperatures due to London dispersion. B) These bonds vanish at low temperatures, as electrons retreat to lower orbitals, weakening the London dispersion.

The interactions between helium atoms arise from London dispersion forces, as illustrated in Figure 3A. At higher temperatures, electrons occupy higher-energy orbitals and are more susceptible to perturbations, leading to polarization and dispersion forces. In contrast, at lower temperatures, helium electrons settle into lower-energy orbitals and are more tightly bound to their nuclei, reducing their polarizability and weakening the dispersion forces.[38] As the temperature continues to drop, these forces diminish to the point where intermolecular interactions become negligible. As shown in Figure 3B, the loss of attractive forces effectively breaks the bonds between atoms. Without these interactions, helium atoms can move independently, resulting in a fluid with zero viscosity—a defining characteristic of superfluidity.[39] In essence, a superfluid is not a conventional fluid but a collection of freely moving, non-interacting particles.

The helium superfluid transition, which occurs near 2.17 K and is known as the λ-point, is experimentally identified by the sudden cessation of boiling. Since bubble formation requires surface tension to contain helium vapor, surface tension that depends on intermolecular attractions, the disappearance of bubbles indicates the loss of these interactions. Although 2.17 K is commonly cited as the superfluid transition temperature, this designation may be inaccurate.

As energy is removed from liquid helium, its temperature decreases, and the intermolecular bonds begin to break due to the weakening and disruption of London dispersion forces. Because breaking these bonds requires energy, the process further lowers the liquid's temperature. As a result, the system cannot remain at a fixed temperature during the transition; instead, it undergoes a gradual change over a temperature range. This range can be approximately identified by the curvature change in the helium specific heat curve, as shown in Figure 4. In a homogeneous liquid, specific heat typically decreases smoothly from point A as energy is removed. Based on this behavior, the curve would be expected to continue its downward trend from A through B to D, as indicated by the red curve extension. However, a deviation occurs at point B: the sharp upward curvature from B to C reflects a dramatic increase in specific heat, indicating a significant phase transformation within the liquid.

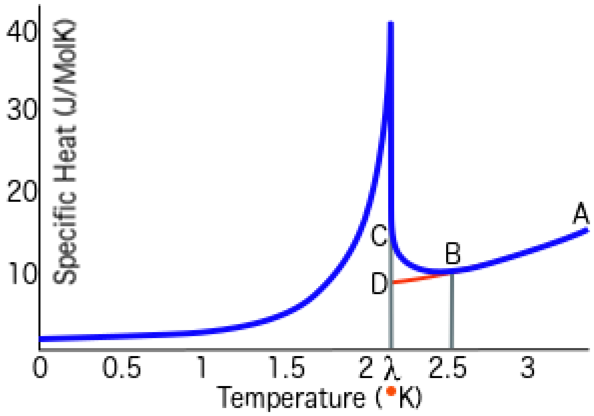

Figure 4: Identifying the temperature range of the helium-4 superfluid transition. The blue curve depicts the specific heat of helium-4 as a function of temperature. The change in curvature between points B and C suggests that the transition begins before the λ-point at approximately 2.17 K.

The significantly high specific heat to the left of the λ-point indicates that molecules in the superfluid phase possess greater specific heat than those in the normal liquid phase. This elevated specific heat may result from the presence of unbound, freely moving molecules that can absorb more kinetic energy, thereby contributing to the overall heat capacity. Consequently, the rising specific heat observed to the right of the λ-point suggests the early emergence of superfluid molecules, implying that the transition begins before the λ-point, specifically when the trend in the specific heat curve first begins to deviate. Therefore, the onset temperature of the superfluid transition should be considered as starting at least from point B, if not earlier. The temperature range for the helium-4 superfluid transition can thus be approximated as spanning from point B to the λ-point. However, the upper limit of this range remains imprecise due to the subtle curvature change that marks the initial onset of the transition.

The Nature of Absolute Zero

The concept of absolute zero was first predicted through Charles's law, which states that the volume of a gas increases proportionally with temperature when pressure is held constant.[40-41] However, the physical meaning of absolute zero remains unclear, largely due to the lack of a clear understanding of temperature itself. According to the third law of thermodynamics, the entropy of a closed system at thermodynamic equilibrium approaches a constant minimum as the temperature approaches absolute zero. At that point, the system is said to reach its lowest possible energy state. But what exactly constitutes this "minimum energy state"?

Einstein's mass–energy equivalence principle[42] suggests that energy encompasses more than just potential, kinetic, or radiative forms; it also includes the intrinsic energy of matter itself, as described by the equation $E = mc^2$. Taken literally, this implies that a system in its absolute minimum energy state would contain no matter at all. In this sense, true absolute zero would not only require the absence of all dynamic energy, but also the complete absence of mass. The underlying confusion lies in the absence of an accurate definition of what constitutes a system's "minimum energy state".

This concept becomes more comprehensible in light of the understanding developed throughout this study. Temperature reflects a system's radiative energy level; thus, absolute zero corresponds to the complete absence of radiation. However, radiative energy is only one of three interrelated components of dynamic energy—the others being kinetic and potential energy. Since these forms continuously transform into one another, true absolute zero cannot be achieved unless all three simultaneously reach their minimum values. If any component remains above its minimum, the system cannot be considered truly at absolute zero.[33]

For an ordinary system on Earth, absolute zero implies three key conditions: the absence of radiation, the complete cessation of particle motion or vibration, and all bonds residing in their lowest possible energy state. In this state, electrons occupy their lowest orbitals, and bond lengths are minimized. However, this does not require electrons to stop revolving within their ground-state orbitals, as this intrinsic motion does not participate in dynamic energy exchanges and therefore has no effect on temperature.

On the other hand, absolute zero may also require that the potential energy between nucleons be at its minimum. For example, a system containing radioactive elements cannot be at absolute zero, as radiation from nuclear decay would still be emitted. It is also important to note that the release of nuclear potential energy depends on a system's physical conditions. On Jupiter, this energy remains locked and is not released under normal circumstances. In contrast, the extreme conditions in the Sun allow nuclear fusion to occur spontaneously, releasing vast amounts of energy and generating intense heat. This explains why the Sun, despite having a similar abundance of hydrogen as Jupiter, reaches extremely high temperatures, while Jupiter remains comparatively cool.

This example highlights a key concept: the accessibility of dynamic energy. Even with comparable amounts of matter, the potential energy between nucleons is accessible in the Sun but not in Jupiter, which lacks the necessary mass to initiate nuclear fusion. According to Einstein's mass-energy equivalence principle, the total energy of a system is intrinsically tied to its mass, as described by the equation:[42]

(7) $E = mc^2$

Here, c denotes the speed of light, and m represents the effective or equivalent mass of the system. This principle shows that mass is a concentrated form of energy, indicating that the total energy of a system encompasses not only dynamic energy, such as potential, kinetic, and radiative components, but also the intrinsic energy stored in matter itself. Accordingly, the total energy of a system can be expressed as the sum of dynamic energy T and matter energy M:

(8) $E = T + M.$

Although matter energy (M) typically does not participate in dynamic interactions, and therefore is not reflected in temperature measurements, it can influence temperature when released from matter. For example, the potential energy stored in hydrogen remains part of the matter energy on Jupiter, but in the Sun, it is converted into dynamic energy. Indeed, matter energy can be entirely transformed into other forms. In positron–electron annihilation, for instance, the total mass of both particles is converted into pure radiative energy. Likewise, any fundamental particle can annihilate with its corresponding antiparticle, releasing the full energy content of the matter. Conversely, in pair production, high-energy photons interacting near an atomic nucleus can generate an electron–positron pair, demonstrating the creation of matter from radiation.

These examples underscore the importance of distinguishing between matter energy and dynamic energy. While M represents the intrinsic energy stored in matter, T refers to the accessible dynamic energy, such as kinetic, potential, and radiative energy, available under the system's current conditions. These two forms of energy can convert into one another when permitted by the system's state, highlighting the context-dependent and transformative nature of energy in physical systems. Accordingly, absolute zero can be understood as a state in which dynamic energy (T) is entirely depleted, while matter energy (M) remains present but inaccessible.

Entropy Can Decrease

Entropy is defined as a logarithmic measure of the number of accessible microstates of a system. If the system has a total of N accessible microstates, the entropy of the system can be expressed as:

(9) $S = k_B ln(N)$

In this definition, k_B denotes the Boltzmann constant. This is called the statistical definition of entropy. The thermodynamic definition is that the change in a system's entropy is the infinitesimal amount of heat transferred from the surroundings to the system during a reversible process divided by the system's instantaneous temperature at the time of transfer.

Although Boltzmann is often credited with establishing an equivalence between the thermodynamic and statistical definitions, the two are fundamentally distinct. This difference becomes especially evident at absolute zero, where a system occupies only a single microstate ($N = 1$), the ground state, resulting in zero entropy according to Definition 9. In contrast, the thermodynamic definition predicts a different outcome: as temperature approaches zero, its reciprocal diverges to infinity, causing the entropy to also diverge toward infinity. This discrepancy underscores a fundamental mismatch between the statistical and thermodynamic formulations of entropy.

The second law of thermodynamics, which asserts that entropy never decreases,[43] is often regarded as a universal principle. However, this assumption merits re-examination. The evolution of systems in the universe does not invariably follow the single, unidirectional trajectory implied by the second law of thermodynamics; it can also exhibit periodic oscillations, such as the swing of a pendulum. Furthermore, entropy can decrease in certain systems, even in isolated cases.[44] Entropy increases are typically observed in systems where repulsive forces dominate the interactions. However, in systems governed by attractive forces, entropy can decrease.

One such example is supercooled water. Supercooled water is liquid water below its freezing point that has not solidified yet. When disturbed, the water begins to freeze. This can occur even in an isolated environment. As it freezes into ice, it releases heat—the potential energy associated with the formation of intermolecular bonds. This released heat is absorbed by the container, warming it. In this case, heat flows from the colder water to the warmer container, which is the opposite direction of heat flow when ice is melting in a cup of water at room temperature. Because the freedom of molecular motion is constrained by bond formation, reducing the number of accessible microstates, the system's entropy decreases according to the statistical definition (9).

For another example, consider a simple experiment involving an isolated system where water at 0 °C is mixed with ice initially below 0 °C. As the ice warms to 0 °C, some of the water may freeze. According to Definition 9, the overall entropy of the system can decrease because the formation of additional ice restricts molecular motion and reduces the number of accessible microstates. A similar entropy reduction is observed during the crystallization of sodium acetate, which can occur in a sealed container without any energy exchange with the surroundings. Likewise, sugar crystals may slowly form in a closed bottle of honey over time, representing decreases in entropy.

All the above examples of entropy reduction occur when attractive forces guide molecular or microscopic organization. Beyond Coulomb interactions, gravity also drives decreases in entropy. For instance, raw, unhomogenized milk left undisturbed separates into layers, with cream rising and skim milk sinking—a shift from a mixed, higher-entropy state to a stratified, lower-entropy one. Similar density-driven stratification is seen when mixed paint settles over time. On much larger scales, gravity shapes the layered interiors of celestial bodies, such as Earth's differentiated core and mantle. Even in the atmosphere, which locally behaves like a well-mixed gas with high entropy, gravitational effects produce large-scale stratification into distinct layers.

Stars, galaxies, and other celestial bodies are thought to emerge from vast cosmic gas clouds that initially possess high disorder and a multitude of accessible microstates. Under the influence of gravity, these clouds collapse, concentrating matter toward their centers of mass and producing more organized structures such as planets, stars, neutron stars, and black holes. Observational evidence indicates that the universe tends to evolve toward increasingly structured configurations, rather than toward the traditional "heat death". Why does the universe not behave as the second law of thermodynamics might predict? The answer is not that cosmic evolution has yet to reach a mature stage, but rather that the second law is not the universally fundamental principle it is often assumed to be.

More importantly, the second law fails to capture the fundamental character of universal dynamics—the continuous transformation and redistribution of energy. This essential principle is more accurately expressed by the **Restoration Principle**.[44] In accordance with Einstein's mass–energy equivalence, all entities in the universe are forms of energy, with matter itself representing a concentrated manifestation. The evolution of any system is therefore driven by transformations of its energy.

These transformations exhibit an inherent tendency toward balance, characterized by a stable ratio among different energy forms at a given total energy. Such a balance emerges through continuous transformations that enhance dynamic stability. It reflects the interplay of competing internal drives, with the dominant force guiding redistribution to minimize potential energy while conserving total energy. Through this process, systems establish or restore balanced distributions of energy, resulting either in progressive development or in oscillations around equilibrium.

In this way, the Restoration Principle unifies entropy-increasing, entropy-decreasing, and oscillatory behaviors, providing a more fundamental framework for universal evolution. By contrast, the classical concept of entropy emphasizes the dispersal of energy—a tendency that holds in systems dominated by repulsive interactions but can reverse when attractive interactions prevail. The second law of thermodynamics, therefore, accounts for only a limited subset of natural processes, rather than the full spectrum of the universe's dynamic behavior.

The Cause of Brownian Motion

The Brownian motion of Clarkia pulchella pollen in water is not a unique case but a typical phenomenon observed at the microscopic scale.[45] Albert Einstein successfully modeled this motion statistically using a random walk framework, proposing that the erratic movement of particles results from collisions with randomly moving molecules in the fluid. However, despite this widely accepted explanation, the underlying mechanism driving Brownian motion remains not fully understood.

To evaluate the proposed theory, we can estimate the velocity required for a water molecule to impart observable Brownian motion to a pollen grain. Consider a pollen grain initially at rest. Suppose it is struck by a single water molecule traveling at velocity *v*. To maximize the estimated momentum transfer, assume the water molecule rebounds with the same speed in the opposite direction, resulting in a complete momentum transfer to the pollen grain. The mass of a water molecule is approximately 2.99 × 10^{-26} kg. The change in momentum of the water molecule due to this elastic collision is:

$$(10) \quad \Delta P_{water} = v \times 2 \times m = v \times 5.98 \times 10^{-26}\ kg.m/s$$

The pollen grain of *Clarkia pulchella* typically measures between 50 - 100 x 10^{-6} m in diameter. For a conservative estimate, we use a smaller diameter of 40 x 10^{-6} m, corresponding to a volume of 6.4 x 10^{-14} m^3. Since the pollen is suspended in water, its density can reasonably be assumed to be close to that of water, about 1000 kg/m^3 at room temperature. Suppose the pollen acquires a velocity of 300 x 10^{-9} m/s, a speed that is barely detectable by the naked eye under a microscope, as the distance moved in a second is already less than the wavelength range of visible light (380-750 x 10^{-9} m). In other words, the actual speed of pollen observed by Brown was likely greater than this threshold. Following a collision, the pollen would gain a momentum of approximately 1.92 x 10^{-18} kg•m/s. This momentum should correspond to the change in momentum imparted by the colliding water molecule:

$$(11) \quad v \times 5.98 \times 10^{-26} = 1.92 \times 10^{-18}$$

So, to push the pollen at the minimum detectable velocity of 300 x 10^{-9} m/s, the speed of a water molecule must be greater than:

$$(12) \quad v = 3.21 \times 10^{7}\ m/s$$

This velocity is greater than 10% of the speed of light. At room temperature, the average velocity of water molecules, derived from the kinetic energy distribution, is approximately 590 m/s.[46] This value is consistent with the speed of sound in water (~1,500 m/s), which can be considered an upper bound for molecular velocity, as sound propagation depends on molecular interactions. For comparison, the average velocity of air molecules is less than 1,200 m/s. Given that water is significantly more viscous than air, the motion of water molecules is even more restricted. The required speed in this scenario is four orders of magnitude greater than the actual molecular speed. Even under this highly conservative estimate, the speed required for a water molecule is far beyond what is physically achievable. Therefore, the velocity needed to explain Brownian motion through direct molecular impacts is physically implausible.[47]

In contrast, the concept of transimpacts provides a more plausible explanation.[30] Transimpacts involve significantly more forceful interactions than the random motion of individual molecules. When a transimpact occurs between a pollen grain and an adjacent water molecule, it can generate strong repulsive forces that effectively push the particles apart, offering a more credible mechanism for the observable dynamics of Brownian motion. Indeed, the random motion of water molecules itself originates from transimpacts. Thus, the apparent randomness in the motion of both water molecules and pollen grains can ultimately be traced back to the underlying transimpact interactions.

The Process Driving Crookes Radiometers

Transimpacts also offer a compelling explanation for the rotation of Crookes radiometers.[30] A Crookes radiometer consists of a low-pressure glass bulb containing a set of vanes mounted on a low-friction spindle.[48] Each vane is black on one side and white on the other. When exposed to light, the vanes begin to spin, with the black sides retreating from the light source. The rotation speed increases with light intensity. The mechanism behind this motion has been debated for centuries. The device's inventor, William Crookes,[49] originally attributed the rotation to photon pressure, as predicted by James Clerk Maxwell.[50] However, this explanation fails on two key points: first, if photon pressure were the cause, the vanes would rotate in the opposite direction due to the higher reflectivity of the white side; second, the motion should increase in a stronger vacuum. In reality, the vanes remain motionless in a hard vacuum. Maximum rotation is observed at low but nonzero pressure, around one Pascal.

Numerous theories attribute the operation of the Crookes radiometer to aerodynamic effects or pressure differentials between the vanes' surfaces or along their edges.[51-56] However, these air-based explanations fail to account for a critical observation: the rapid onset of rotation, especially the pronounced initial acceleration. According to Newton’s second law, acceleration is directly proportional to the net applied force. Thus, a strong initial acceleration implies the presence of a significant driving force at the very beginning. For the stationary vanes to start rotating, this force must first overcome the static friction at the spindle. In models based on air pressure or thermal transpiration, such pressure differences build up gradually as the gas heats. This would predict a slow increase in acceleration, starting from zero. Yet, this is not observed. Instead, experiments consistently show the maximum acceleration occurring immediately after exposure to light, contradicting the gradual buildup expected from air-based mechanisms.

Moreover, these theories fail to account for observations from cooling experiments. When a Crookes radiometer is placed in a refrigerator or exposed to a cold substance like evaporating alcohol, the vanes immediately begin rotating in the reverse direction, even as energy is being removed from the system. Under such conditions, the motion of air molecules slows, making it even less likely that air-based driving forces could overcome the resistance needed to initiate rotation. Yet, the vanes briefly spin before coming to rest. This behavior is difficult to reconcile with conventional gas dynamics, suggesting that a different underlying mechanism is at play.

When light strikes the radiometer, atomic electron transitions and transimpacts occur instantaneously. During a transimpact, an air molecule near the vane surface is repelled, transferring momentum to the vane and exerting a force on it. These transimpacts occur more frequently on the black side of the vane due to its higher light absorption efficiency, resulting in an imbalance of forces between the two sides. Because transimpacts respond immediately to incident light, this theory predicts the highest driving force, and thus the greatest acceleration, at the very onset of illumination. As the vanes begin to rotate, air resistance increases, gradually reducing acceleration over time.

Experiments were conducted to test this prediction, and the results closely align with theoretical expectations, as illustrated in Figure 5. These outcomes provide strong empirical support for the transimpact theory. As indicated by the red curve, the driving force reaches its peak at the initial moment of illumination. As rotational speed increases, air resistance builds up, thereby reducing the net driving force. Eventually, the resistive force counterbalances the driving force, leading to a steady-state rotational speed.

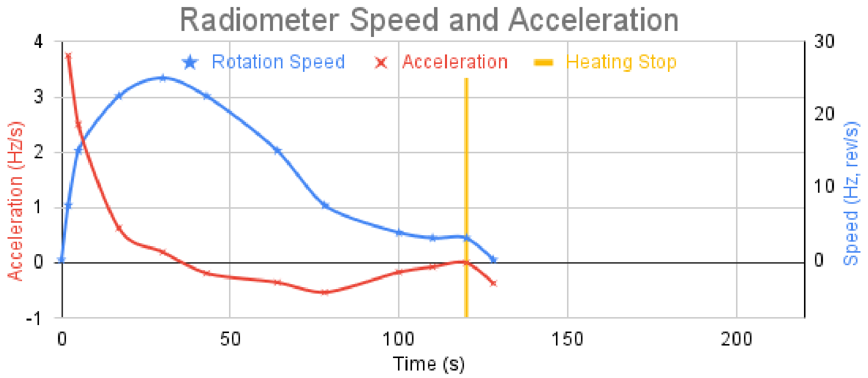

Figure 5: Radiometer speed and acceleration in a high-power flashlight experiment.

The theory also predicts a brief period of reverse rotation when the light source is removed. In this scenario, the black side, being a more efficient thermal emitter, radiates heat more quickly than the white side, creating a temporary asymmetry in transimpacts that results in a reverse driving force. This effect helps explain the reverse rotation seen in cooling experiments, such as when radiometers are placed in refrigerators. Notably, rapid reverse rotation was recorded in microwave experiments: after heating a radiometer in a microwave for a few seconds and quickly removing it, we observed reverse rotation speeds of up to 7 revolutions per second. However, conducting such microwave experiments carries safety risks. During a second attempt, the metal component connecting the vanes caused the radiometer to burn out. For this reason, we advise against replicating this experiment. Fortunately, a YouTube video documenting a similar microwave heating process is available for reference.[57]

Another noteworthy observation is a brief deceleration period immediately following the initial peak in rotational speed. This likely results from a reduced asymmetry in transimpacts as the white side of the vanes warms up due to both direct absorption and internal heat conduction from the black side. This phenomenon may not be as observable in experiments using less intense light sources.

Misconceptions about Electrical Resistance

Misconceptions about electrical resistance often stem from fundamental misunderstandings of particle vibrations, which can also contribute to confusion about the nature of superconductivity. Most contemporary theories trace back to the Drude model.[58] This model proposes that atoms in a metallic conductor are bound by metallic bonds, forming a lattice through which a "sea of free electrons" moves, giving rise to an electric current. Electrical resistance, in this framework, is attributed to collisions between these mobile electrons and the vibrating ions of the crystal lattice. Each collision disrupts the electron's motion and dissipates a portion of its energy, thereby resulting in resistance.

According to this view, metallic bonds are responsible for the cohesion within metal crystals. In metals, valence electrons detach from their parent atoms and form a "sea of electrons" that flows freely among the positively charged atomic nuclei. This electron sea acts as a cohesive medium, binding the nuclei together and giving rise to metallic bonding. The structural stability of metal crystals depends on the strength of these metallic bonds.

However, this raises an important question: What would happen if the sea of electrons were removed from a metal crystal, such as during the flow of an electric current? Without this electron sea, the positively charged atomic nuclei that make up the crystal lattice would repel one another, leading to structural disintegration. The idea of a freely moving electron sea implies that the bonding "glue" within the crystal is not localized. This casts doubt on how the metal lattice can maintain its structural integrity when held together by such a seemingly unstable and delocalized force.

In reality, metals exhibit highly stable structures and can withstand substantial shearing and tensile forces. This stability suggests that the widely accepted concepts of the electron sea and metallic bonding may require further scrutiny. As an alternative, the concept of *compression bonds* is proposed to explain the structural integrity of metals.[37] When atoms are brought close together, their valence electron clouds can deform, resulting in an uneven distribution of electron density in different directions. This anisotropy creates localized electric fields, which in turn generate attractive forces between atoms. Such compression bonding may also be responsible for the cohesion observed in helium solids and metallic hydrogen.

Furthermore, if the Drude model were accurate, one would expect high-density materials to exhibit greater electrical resistance. Under increased confining pressure, atoms are forced closer together, which should, in theory, increase the frequency of collisions between electrons and the lattice, leading to higher resistivity. However, experimental evidence shows the opposite: electrical resistivity typically decreases as pressure increases, indicating a negative correlation between pressure and resistivity.[59-61]

The widely accepted BCS (Bardeen-Cooper-Schrieffer) theory of superconductivity is fundamentally rooted in the conventional model of electrical resistance. According to BCS theory, superconductivity emerges when electrons form Cooper pairs through electron-phonon interactions at low temperatures, effectively minimizing electron vibrations and eliminating resistance. However, since 1986, superconductors have been discovered that operate at increasingly higher temperatures, far beyond the theoretical limits predicted by BCS theory. Notably, many of these high-temperature superconductors are observed under high pressure, a factor that BCS theory does not adequately explain in terms of its positive impact on superconductivity. This discrepancy may point to flawed assumptions in the traditional understanding of electrical resistance.

Unified Theory of Resistivity and Superconductivity

The inability of existing theories to account for resistivity and superconductivity under high pressure may not be coincidental, but rather a consequence of flawed assumptions underlying the conventional collision-based model of electrical resistance and the notion of the electron sea. These conceptual inaccuracies may have steered research in unproductive directions, hindering both theoretical understanding and practical advancements, especially in the quest for room-temperature superconductors. To address these limitations, a new theoretical framework has been proposed, offering a unified theory that integrates both electrical resistivity and superconductivity into a single, cohesive model.[62]

Rather than treating resistivity and superconductivity as fundamentally distinct phenomena, we propose that they arise from the same underlying physical mechanism. There are no freely moving electrons in conductors. Because of their negative charge, electrons must conform to quantized energy levels and are typically confined to atomic orbitals. When an electron acquires sufficient energy, it can transition to a higher-energy state that allows it to move between neighboring molecules via a shared path, referred to here as an *electron tunnel*. The extent of connectivity among these electron tunnels determines whether a material behaves as a conductor, semiconductor, or insulator. Electrical resistance arises from the energy required to elevate an electron from its valence orbital into an electron tunnel. The size of this energy gap defines the material's resistivity: the smaller the gap, the lower the resistance. In superconductors, this gap is effectively zero, enabling resistance-free electron transport.

As the temperature increases, thermal expansion causes the distance between molecules to grow, widening the energy gap and increasing electrical resistivity. Conversely, as temperature decreases, molecular spacing contracts, narrowing the energy gap and lowering resistivity. Conventional superconductors at low temperatures represent the extreme of this trend, where the energy gap effectively decreases to zero. Similarly, applying high pressure reduces molecular spacing, which also narrows the energy gap and decreases resistivity. This explains why resistivity drops under pressure and why many superconductors are only discovered at extremely high pressures. In insulators, conduction is blocked by large energy gaps between disconnected tunneling paths. High pressure can reduce these gaps, enabling conductivity. Indeed, some superconductors have been created by compressing insulating materials.

This theory unifies insulators, conductors, and superconductors as dynamic resistance states of matter, governed by variations in pressure and temperature. The differences among these states arise from the extent and connectivity of electron tunneling pathways, as well as the energy gaps between these pathways and the valence orbitals.

A key insight from this theory for synthesizing room-temperature superconductors is the importance of reducing molecular spacing. The main obstacle is the natural repulsion between molecules. While external pressure can overcome this repulsion, as in many current high-temperature superconductors, it is impractical for most applications. An alternative approach may be to design molecular structures that harness specific intermolecular attractions to counteract repulsion and achieve the desired compression.

Conclusions

The role of particle vibration has been overestimated in many physical processes, leading to misconceptions across a variety of phenomena, such as temperature representation, Brownian motion, and electrical resistance, particularly those related to thermodynamics. Many of these concepts are foundational, underpinning broad areas of science and technology. As a result, such misconceptions have already hindered progress in several fields, with the potential to continue doing so if left uncorrected. With the introduction of new concepts, such as *transimpact*, *dynamic energy*, and *compression bond*, these misunderstandings can be more effectively addressed. These insights help resolve longstanding scientific puzzles, including the rotation of Crookes radiometers, the true cause of electrical resistance, and the mechanism behind superconductivity. More importantly, they have the potential to significantly deepen scientific understanding and accelerate future research and innovation, including the development of room-temperature superconductors.

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- 12/30/2022: Initial Post on Stanford Site
- 11/02/2025: Published on Zenodo
- 12/17/2025: Adding Links to Summaries of Related Articles

Links to Summaries of Related Articles

- https://cs.stanford.edu/people/zjl/abstract.html, PDF
- https://sites.google.com/view/zjl/abstracts, PDF
- https://xenon.stanford.edu/~zjl/abstract.html, PDF
- https://doi.org/10.5281/zenodo.17967154, PDF

Further Literature

- Misconceptions in Thermodynamics (PDF: DOI) (中文: DOI)
- The Mechanism Driving Crookes Radiometers (PDF: DOI) (中文: DOI)
- The Cause of Brownian Motion (PDF: DOI) (中文: DOI)
- Can Temperature Represent Average Kinetic Energy? (PDF: DOI) (中文: DOI)
- The Nature of Absolute Zero Temperature (PDF: DOI) (中文: DOI)
- The Triangle of Energy Transformation (PDF: DOI) (中文: DOI)
- Is Thermal Expansion Due to Particle Vibration? (PDF: DOI) (中文: DOI)
- Superfluids Are Not Fluids (PDF: DOI) (中文: DOI)
- Why a Phase Transition Temperature Remains Constant (PDF: DOI) (中文: DOI)
- What Causes Friction to Produce Heat? (PDF: DOI) (中文: DOI)
- The Easiest Way to Grasp Entropy (PDF: DOI) (中文: DOI)
- Entropy Can Decrease (PDF: DOI) (中文: DOI)
- The Restoration Principle (PDF: DOI) (中文: DOI)
- Is There a Sea of Free Electrons in Metals? (PDF: DOI) (中文: DOI)

- Electron Tunnel (PDF: DOI) (中文: DOI)
- Unified Theory of Low and High-Temperature Superconductivity (PDF: DOI) (中文: DOI)
- LK-99 Limitations and Significances (PDF: DOI) (中文: DOI)
- Superconductor Origin of Earth's Magnetic Field (PDF: DOI) (中文: DOI)
- Fundamental Problems about Mass (PDF: DOI) (中文: DOI)
- The Evolution from the Law of Gravitation to General Relativity (PDF: DOI) (中文: DOI)
- The Simplest Derivation of $E = mc^2$ (PDF: DOI) (中文: DOI)
- How to Understand Relativity (PDF: DOI) (中文: DOI)
- Mathematics Is Not Science (PDF: DOI) (中文: DOI)
- Tidal Energy Is Not Renewable (PDF: DOI) (中文: DOI)
- AI Contamination (PDF) (中文)
- DeepSeek pk ChatGPT (PDF) (中文)

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