Article

Energy Conservation Issues Caused by the Causal Relationship Between the Work of Cyclic Phase Transition Magnetization and the Change in Internal Energy of Objects

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Energy Conservation Issues Caused by the Causal Relationship Between the Work of Cyclic Phase Transition Magnetization and the Change in Internal Energy of Objects

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Abstract

This paper separately analyzes the thermodynamic processes of adiabatic superconducting phase transition in superconductors and adiabatic Curie phase transition in ferromagnets in magnetic fields. Through analysis, it is concluded that for an object undergoing a phase transition cycle, when the accumulated magnetization work is zero, the overall internal energy of the adiabatic phase transition system is conserved. However, in the model, the accumulated mechanical work done on the permanent magnet is not zero, which leads to non-conservation of energy in the model, contradicting the law of conservation of energy. This indicates that the law of conservation of energy also has exceptions and is not absolute.

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1. Background Theory

This analysis is based on the following foundational theories:

When a superconductor in a magnetic field enters the superconducting state, it expels the magnetic field, achieving electromagnetic shielding, i.e., the Meissner effect. [1,2]

The superconducting phase transition occurs due to a reduction in quantum condensation energy levels, fundamentally triggered by temperature changes. According to energy conservation, after a complete phase transition cycle, the object returns to its initial state, and the cumulative heat exchange with the external environment is zero. Here, a phase transition cycle refers to the process: superconducting state → normal state → superconducting state, or vice versa.

Based on magnetic medium thermodynamics, for an object with magnetization intensity M in a magnetic field H (ignoring the excited field), the magnetization work done by the magnetic field on the object is: $W = \mu_0 \int HdM$. [1–3] Here, μ_0 is the vacuum permeability ($4\pi\times10^{-7}$H/m).

According to the first law of thermodynamics, $\Delta E = Q + W$, internal energy is a state function. Regardless of how the state changes during the process, if the object fully returns to its initial state (including temperature), its internal energy is conserved.

Analogous to an ideal gas with the equation of state ${}_1V_1/T_1 = p_2V_2/T_2$, compressing or decompressing a fixed amount of gas in an adiabatic chamber can cause temperature changes. When the gas returns to its original state, the temperature resets, and no net energy is consumed, with zero net work done by the external environment.

For simplicity, this theoretical analysis temporarily neglects the following factors: assuming perfect magnetic shielding in the superconducting state; adiabatic phase transitions with no heat exchange; magnetic hysteresis losses and other dissipative effects; energy consumption due to force displacement; and thermodynamic volume work (e.g., pV work) from volume changes caused by temperature or magnetic field variations (e.g., magnetostriction). These are addressed collectively at the end of the article.

2. Analysis Under a Fixed Magnetic Field

Figure 1 illustrates schematic diagrams of the two phase transition cycles, where (a) represents the superconducting phase transition and (b) represents the Curie phase transition.

First, based on magnetic medium thermodynamics and superconductivity thermodynamics, both phase transitions exhibit extremely similar characteristics: temperature changes induce phase transitions, and the internal magnetization state depends solely on the phase state, independent of the order of magnetic field application. Moreover, the magnetization work and heat absorption/release fully adhere to the thermodynamic properties of phase transitions. After a complete cycle, the total magnetization work is zero, the cumulative heat exchange with the environment is zero, and the first law of thermodynamics is satisfied.

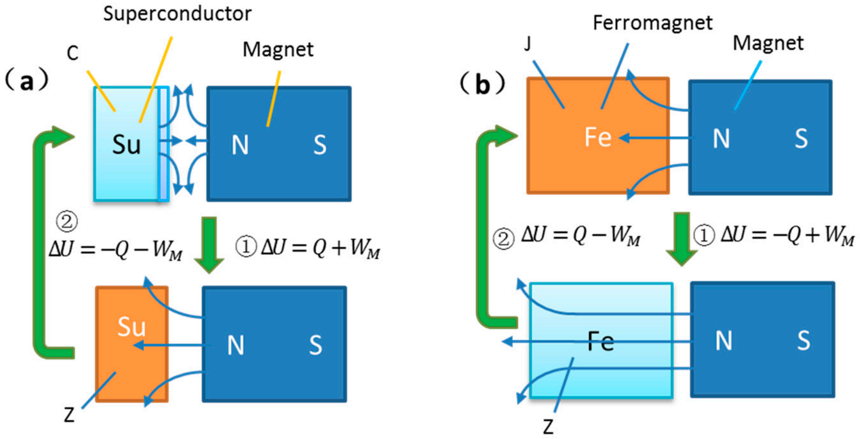

Figure 1. **(a)** is a schematic diagram of the superconducting phase transition cycle in a magnetic field. In the diagram, ΔU represents the change in internal energy of the superconductor, Q is the heat absorbed by the superconductor, and W_M is the magnetization work received by the superconductor. **(b)** is a schematic diagram of the Curie phase transition cycle in a magnetic field. In the diagram, ΔU represents the change in internal energy of the Curie ferromagnet, Q is the heat absorbed by the Curie ferromagnet, and W_M is the magnetization work received by the Curie ferromagnet.

3. Adiabatic Phase Transition Realized via Thermodynamic Work Conversion in a Piston-Equipped Adiabatic Chamber

Although thermodynamics theory proves that no substance truly consumes energy during phase transitions—similarly for superconducting phase transitions, which are entirely temperature-driven and involve temporary heat exchange—a complete cycle results in no net energy consumption and conserved internal energy. In an adiabatic environment, the internal energy of the system remains unchanged after a cycle. To address skepticism, this paper introduces an adiabatic device model controlled by mechanical work to visually demonstrate that phase transitions are solely determined by temperature changes and do not truly consume energy.

Figure 2 intuitively displays the phase transition process using a piston-equipped adiabatic chamber model, where (a) represents the superconducting phase transition and (b) represents the Curie phase transition in a ferromagnet.

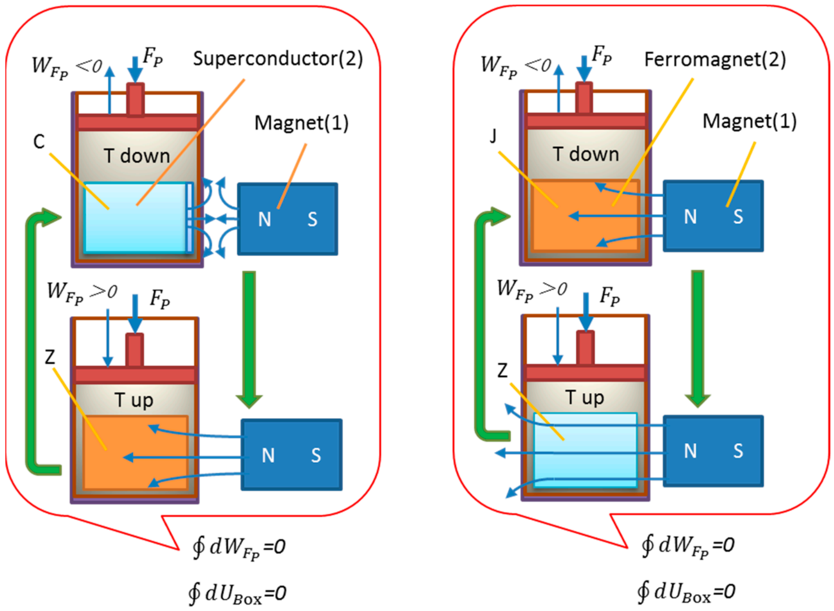

Figure 2. **(a)** A phase transition superconductor is placed in an adiabatic chamber with a piston. Compression and release of the piston cause temperature increases or decreases in the ideal gas inside, realizing the superconducting cyclic phase transition. **(b)** Similar to **(a)**, but for the Curie phase transition, with a Curie ferromagnet inside the chamber. Here, C denotes the superconducting state of the superconductor, Z denotes the normal state of the superconductor or Curie ferromagnet, and J denotes the ferromagnetic state of the Curie ferromagnet; $\mathrm{F_P}$ represents the force compressing the piston, and $\mathrm{W_{F_P}}$ denotes the work done by compressing or releasing the piston.

4. Thermodynamic Analysis of the Relationship Between Magnetization Work and Internal Energy Change in Phase-Transition Materials

Figure 3 presents a slightly modified thermodynamic model of the magnetic field phase transition cycle based on Figure 1. Unlike Figure 1, during the phase transition, the permanent magnet's magnetic field approaches or recedes accordingly, further analyzing the heat changes in the phase transition object itself and the variations in magnetization work.

(a) Thermodynamic Analysis of Superconducting Phase Transition

The phase transition object is placed in the adiabatic chamber of Figure 2, indicating an adiabatic environment for the entire process. The required temperature changes for phase transition are achieved by compressing the gas, visually demonstrating that the process does not truly consume energy. To intuitively represent heat absorption or release by the phase-transitioning material and the sign of magnetization work, the following symbols denote only the positive values of physical parameters, with negative signs indicating heat release or negative work by the material. In Figure 3, Q_{PT} represents the heat absorbed during the phase transition of the superconductor without a magnetic field, Q_M is the heat absorbed after the superconductor is magnetized by the field, and Q is the total heat absorbed during the phase transition in the magnetic field, thus:

$$Q = Q_{PT} + Q_M$$

When the magnetic field is removed in the superconducting state, although the supercurrent vanishes without energy consumption, the absence of magnetic field inhibition causes the energy levels of the superconductor to tend toward a lower state, with an increased energy gap. The superconductor "relaxes" from a higher-energy excited state spectrum to a lower-energy, more stable ground state spectrum. The superconductor would normally cool down, but in an adiabatic environment, it absorbs heat.

It can be seen that Step ④ in Figure 3a is identical to Step ② in Figure 1a, while Steps ①, ②, and ③ together equivalent to Step ① in Figure 1a. In Steps ①, ②, and ③, the superconductor starts in the superconducting state. First, the permanent magnet moves away, resulting in positive magnetization work $\Delta U = Q_M + W_M$, accompanied by a decrease in energy levels, absorbing heat in an isothermal environment. Then, it transitions to the normal state in a zero-field condition, with energy levels rising due to phase transition, necessarily absorbing heat from the environment $\Delta U = Q_{PT}$. Finally, in the normal state, the magnetic field is applied, with minimal effect on the paramagnet $\Delta U \approx 0$. In Step ④, the superconductor transitions back to the initial superconducting state in the magnetic field. Here, it experiences negative magnetization work and phase transition simultaneously, both causing a decrease in energy levels and releasing heat to the environment $\Delta U = -Q_{PT} - Q_M - W_M$. Due to phase transition reversibility, this step is entirely the inverse of the first three steps.

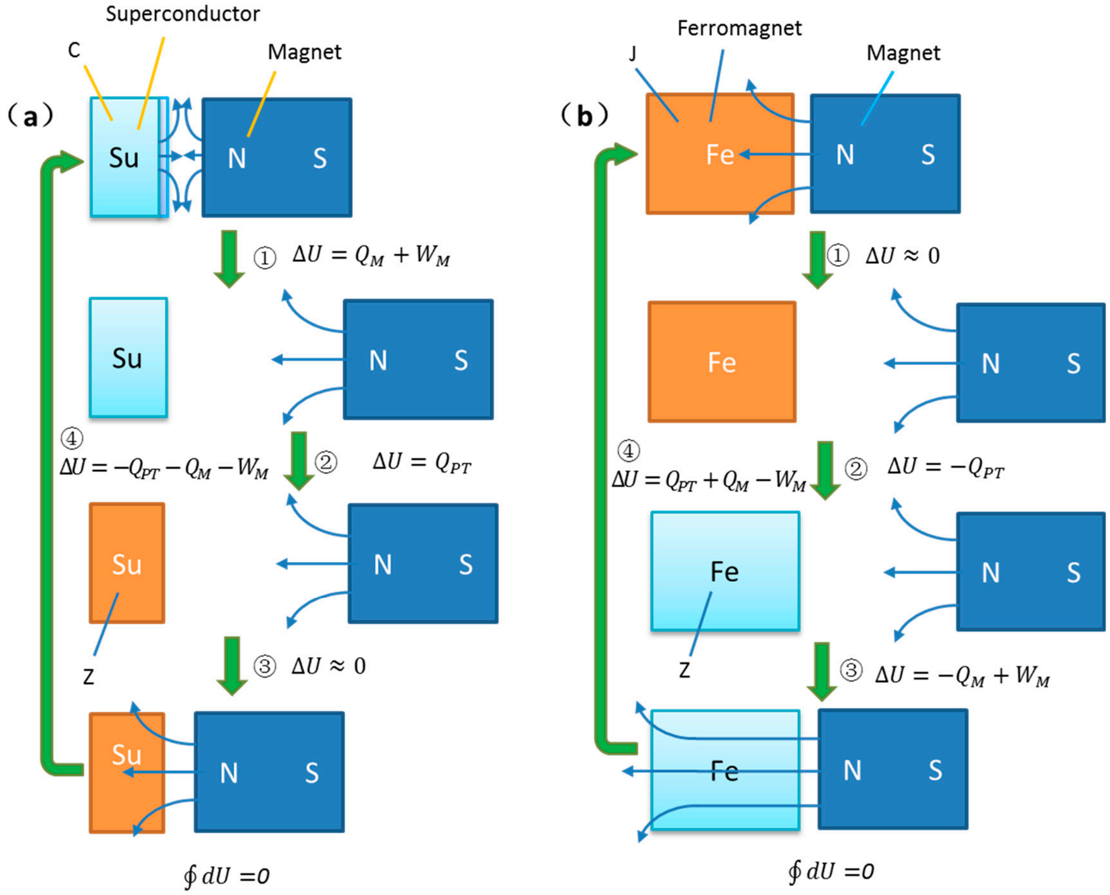

Figure 3. (a) is similar to **Figure 1 (a)**, also a schematic diagram of the superconducting phase transition cycle in a magnetic field. The difference is that when the superconductor is in the superconducting state, the permanent magnet and its magnetic field move away from the superconductor, then the superconductor transitions to the normal state, then the permanent magnet approaches the superconductor again, and then the superconductor returns to the initial superconducting state. In the diagram, U represents the internal energy of the superconductor, Q is the heat absorbed by the superconductor, and W_M is the magnetization work received by the superconductor. **(b)** is similar to **Figure 1 (b)**, and it is also a schematic diagram of the Curie phase transition cycle in a magnetic field. The difference is that when the Curie ferromagnet is in the Curie state, the permanent magnet moves away. Then, the Curie ferromagnet transitions to the normal ferromagnetic state. Subsequently, the permanent magnet approaches the Curie ferromagnet again, and then the Curie ferromagnet returns to the initial Curie state. In the diagram, U represents the internal energy of the Curie ferromagnet, Q is the heat absorbed by the Curie ferromagnet, and W_M is the magnetization work received by the Curie ferromagnet.

Analysis shows that after a complete cycle, the cumulative work done on the superconductor is zero, and the cumulative heat transfer is zero, conserving its internal energy. Assuming the cumulative work done by the piston on the adiabatic chamber is also zero, the internal energy of the gas inside is conserved, and the entire adiabatic phase transition system conserves internal energy.

According to the first law of thermodynamics, $\triangle \boldsymbol{E} = \boldsymbol{Q} + \boldsymbol{W}$ is a state function. Regardless of how work and heat transfer vary during the superconducting phase transition, as long as the initial state is restored, the cumulative work and heat exchange with the environment are zero, internal energy is conserved, verifying the correctness of the derivation.

Through analysis, when the model completes one phase transition cycle, the cumulative work done by the external environment on the superconductor is zero, and the cumulative heat transfer to it is also zero; thus, its internal energy is conserved. Assuming the cumulative work done by the piston on the adiabatic chamber is also zero, then the internal energy of the gas inside the chamber is conserved, and the internal energy of the entire adiabatic phase transition system is conserved.

Simultaneously, according to the first law of thermodynamics, ΔE = Q + W, regardless of how the work and heat transfer between the superconductor and the external environment change during the superconducting phase transition process, as long as it ultimately returns to its initial state, the cumulative work and heat with the external environment are both zero, and the internal energy of the entire system is conserved.

(b) Thermodynamic Analysis of Curie Phase Transition and Comparison with Superconducting Phase Transition

For the Curie phase transition, applying a magnetic field to a ferromagnet orders the magnetic domains, lowering the free energy and producing a magnetocaloric effect where the object releases heat and temperature rises. Conversely, demagnetization increases free energy; if the ferromagnet is in an adiabatic chamber, the temperature inside decreases due to heat absorption by the ferromagnet to raise its free energy, known as the adiabatic demagnetization cooling effect.

It can be seen that Step ④ in Figure 3b is identical to Step ② in Figure 1b, while Steps ①, ②, and ③ together equivalent to Step ① in Figure 1b. In Steps ①, ②, and ③, the Curie ferromagnet starts in the normal state. First, the permanent magnet moves away, with minimal effect on the paramagnet in the normal state $\Delta U \approx 0$. Then, in the zero-field condition, the ferromagnet transitions to the ferromagnetic state, with energy levels decreasing due to phase transition, necessarily releasing heat to the environment $\Delta U = -Q_{PT}$. Next, in the ferromagnetic state, the magnetic field is applied, resulting in positive magnetization work, domain ordering, further lowering of energy levels, and heat release $\Delta U = -Q_M + W_M$. In Step ④, the ferromagnet transitions to the normal state in the magnetic field, with domain disordering raising energy levels, while simultaneously experiencing negative magnetization work, both causing heat absorption from the environment $\Delta U = Q_{PT} + Q_M - W_M$. Due to phase transition reversibility, this step is entirely the inverse of the first three steps.

Analysis shows that after a complete cycle, the cumulative work done on the ferromagnet is zero, and the cumulative heat transfer is zero, conserving its internal energy. Assuming the cumulative work done by the piston on the adiabatic chamber is also zero, the internal energy of the gas inside is conserved, and the entire adiabatic phase transition system conserves internal energy. **This aligns with the results derived from the state function of thermodynamics.**

This indicates that the two phase transitions in a magnetic field are highly similar: both involve magnetization work, but the direction of magnetization work is opposite—positive for the ferromagnet and negative for the diamagnet—due to their inherent properties. The difference lies in the fact that the superconducting phase transition in a magnetic field involves latent heat of phase transition, with abrupt heat release, classifying it as a first-order phase transition; whereas the Curie phase transition, with or without a magnetic field, is a second-order phase transition with no latent heat and continuous heat changes.

The above analysis of the Figure 3b model (Curie ferromagnet) shows that the internal energy of the adiabatic phase transition system remains conserved with no energy dissipation. Yet, for the permanent magnet, cyclic motion induces unidirectional magnetic force work from the ferromagnet's induced field, leading to non-zero cumulative magnetic force work and mechanical work, again contradicting energy conservation.

(c) Causality Between Magnetization Work and Internal Energy Change in Phase Transitions

The analysis above shows that when a superconductor in the superconducting state has the magnetic field removed, it gains positive magnetization work and absorbs heat. Conversely, when transitioning from the normal to superconducting state in a magnetic field, it gains negative work and releases heat due to magnetization work. This differs from the Curie phase transition in ferromagnets, where gaining positive magnetization work in the ferromagnetic state releases heat, and gaining negative work during demagnetization absorbs heat.

Therefore, as long as the phase-change material obtains magnetization work, regardless of positive or negative, it will produce endothermic and exothermic reactions. Therefore, if the internal energy change caused by the phase transition itself is not included, the magnetization work is the fundamental cause of the internal energy change in the phase-change material. Moreover, the transient changes in magnetization work lead to internal energy changes occurring simultaneously.

The Figure 3 processes further demonstrate that after a complete phase transition cycle, the material returns to its initial state with cumulative magnetization work and internal energy exchange both totaling zero, confirming internal energy conservation. This implies that the net internal energy change of the phase-transitioning material depends solely on the final cumulative magnetization work, irrespective of the magnetization process's duration, sequence, or timing. This aligns with the concept of energy as a state function.

5. The Issue of Energy Conservation Arising from Mechanical Energy Changes in Two Phase Transition Models

Through the above analysis, when the model completes one phase transition cycle, the cumulative magnetization work done on the phase transition object is zero, and the internal energy is conserved. The adiabatic phase transition system does not consume external energy, the cumulative energy exchange with the external environment is zero, the internal energy of the phase transition system is conserved, and the internal energy of the entire model is conserved.

However, it is evident that during the operation of the model, the moving permanent magnet is subjected to magnetic work from the magnetic field force. Moreover, due to the intermittent phase transition of the phase transition object, the permanent magnet is only subjected to unidirectional magnetic work from the magnetic field force during its movement. This directly results in a non-zero cumulative magnetic work and a non-zero cumulative mechanical work after one cycle. This directly leads to non-conservation of energy in the model, contradicting the law of energy conservation.

From a logical analysis, since the internal energy change of the phase-transitioning material is exclusively determined by magnetization work (excluding other factors), the mechanical work generated by the permanent magnet during motion does not alter the material's internal energy. Instead, it is a byproduct of the magnetization work's influence on the material's energy state. For instance, if the same magnetic field changes are applied without magnet motion, the phase-transitioning material would experience identical magnetization work and internal energy changes while maintaining energy conservation.

6. Impact of Practical Factors like Hysteresis on Energy

When a superconductor transitions to the superconducting state, becoming diamagnetic, removing the magnetic field may cause hysteresis effects. However, upon heating to the normal state, all hysteresis disappears. In practice, remnant magnetism in superconductors is eliminated by heating-induced quench. Volume changes during phase transitions do not exchange work with the environment, constituting virtual work, and after a cycle, the cumulative volume work is zero. Hysteresis effects in Curie phase transitions for ferromagnets are identical to those in superconductors—no cumulative effects remain after one cycle. Thus, these factors need not be considered and do not affect the analysis.

7. Conclusions

Through thermodynamic analysis of Curie phase transition and superconducting phase transition, this paper concludes that the magnetization work experienced during the phase transition process of an object is the fundamental cause of the change in internal energy of the phase transition substance. Further analysis shows that after one phase transition cycle of the model, the accumulated magnetization work is zero, and the internal energy of the phase transition substance and the entire model is conserved. However, the accumulated mechanical work received by the permanent magnet is not zero, which leads to the entire model's energy no longer being conserved, contradicting the law of conservation of energy. This suggests that the law of conservation of energy also has exceptions and is not absolute.

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