[The Triangle of Energy Transformation]

Liu, Jerry Z.

ZJL@CS.Stanford.EDU

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Introduction

Energy commonly exists in three fundamental forms: **kinetic**, **potential**, and **radiative** energy, known as [Dynamic Energy]. An object in motion possesses kinetic energy. Potential energy arises between interacting bodies subject to forces such as the Coulomb force or gravitational force. When a body accelerates and its associated force field changes, the resulting disturbance emits radiative energy, exemplified by phenomena such as light and gravitational waves.

At the macroscopic level, energy transfer occurs through radiation, conduction, and convection. But what mechanisms underlie these processes at the microscopic scale? One of the hallmarks of quantum systems is their inherent randomness, often regarded as an intrinsic property of quantum particles. Yet this raises a deeper question: how do individual particles acquire the kinetic energy associated with random motion in the first place?

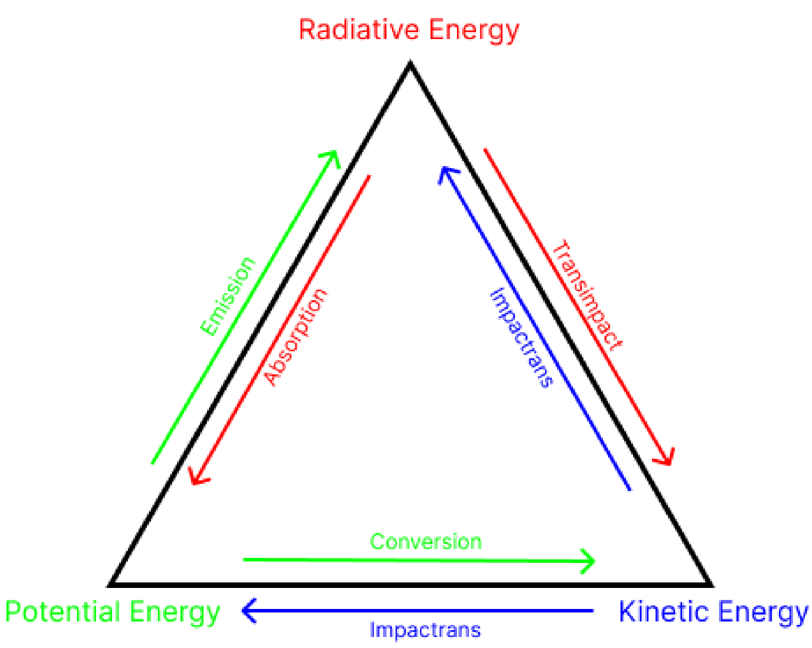

Figure 1: The Triangle of Energy Transformation. Each form of energy is transformed into the other forms along the adjacent edges of the triangle through the mechanisms indicated by the arrows.

This article explores these fundamental questions by examining how energy transforms among three basic forms: radiative, potential, and kinetic energy. Together, these transformation pathways form the components of the **Triangle of Energy Transformation**, as illustrated in Figure 1. These processes represent the underlying mechanisms that drive a system's evolution toward energy equilibrium.

From Radiative Energy to Potential Energy

When a wave travels across the surface of a body of water, it carries and propagates energy. As the wave passes a floating object, the object absorbs part of that energy and oscillates up and down with the wave. Similarly, electromagnetic waves—such as light—also carry energy. When an electromagnetic wave encounters an electron, the electron is driven by the oscillating field and absorbs a portion of the wave's energy. Upon absorbing radiative energy, an electron is excited to a higher orbital in a process known as an atomic electron transition, storing the absorbed energy as potential energy of the orbital electron, as indicated by the **Absorption** path in Figure 1.

Potential energy can also be stored in chemical bonds between atoms or in intermolecular bonds as energy is absorbed. These bonds, like springs, store potential energy when stretched by the absorbed energy. Notably, chemical bonds typically have a much greater capacity to store potential energy than orbital electrons, since atoms or molecules are usually more than three orders of magnitude heavier than electrons.

The Kinetic-Energy Origin of Particle Random Motion

Coulomb attraction typically occurs between nearby atoms or molecules. However, when they become too close, valence electron–electron repulsion increases rapidly. A balance between these opposing forces is established at a characteristic spacing known as the van der Waals distance. This equilibrium will be disrupted during atomic electron transitions. Upon absorbing energy, an electron jumps to a higher orbital—usually within a few nanoseconds or less. As the electron cloud expands, the volume of the host atom increases, reducing the distance to adjacent atoms. This sudden decrease in spacing disturbs the established equilibrium, leading to an increase in repulsive forces that push the atoms apart. This phenomenon is known as **Transimpact**, as illustrated in Figure 2.

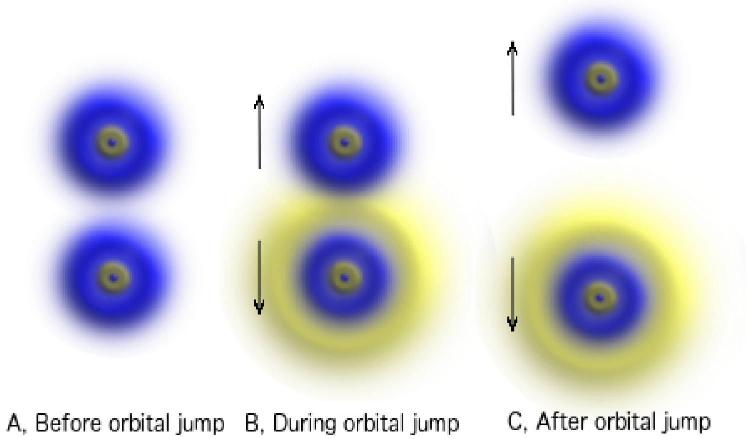

Figure 2: Transimpact due to an atomic electron transition.

Transimpacts are explosive, similar to the sudden burst of popcorn. The resulting momentum delivers significant kinetic energy to adjacent particles, driving them apart and triggering or amplifying their motion. Atomic electron transitions are routine processes at the microscopic scale, continuously occurring in all matter. Consequently, transimpacts are common interactions that influence many aspects of physics, particularly in thermodynamics. They also serve as the underlying mechanism behind phenomena such as Brownian motion, phase transitions, and the operation of the Crookes radiometer. Therefore, the kinetic energy of microscopic particles originates ultimately from radiative energy through transimpacts, representing an energy transformation pathway from radiative to kinetic forms, as illustrated in Figure 1.

It is widely accepted that particles vibrate more slowly at lower temperatures. This relationship can be indirectly confirmed by observing how temperature correlates with the intensity of Brownian motion and the rates of chemical reactions. However, if particles exhibit little or no vibration at absolute zero, a question arises: how do they acquire the kinetic energy necessary for vibration as temperature increases from absolute zero? **Transimpacts** may provide a plausible mechanism, enabling particles to gain vibrational kinetic energy gradually as energy is introduced.

From Potential Energy to Other Forms

An electron can also move to a lower orbital in an atomic electron transition, during which the stored potential energy is released as electromagnetic radiation. This process represents the transformation of energy from potential to radiative form and is known as **Emission**, as shown in Figure 1. Similarly, potential energy stored in bonds between charged particles can be released as radiation when the bonds contract.

When an electron transitions between orbitals, its kinetic energy changes in tandem with its potential energy during the **Conversion** process, as illustrated in Figure 1. This type of energy conversion is not limited to charged particles at microscopic scales; it also occurs in macroscopic systems governed by gravitational forces—for example, during the continuous exchange between potential and kinetic energy in a swinging pendulum.

It is a common misconception that a pendulum does not emit any radiation. In reality, a pendulum also radiates energy in the form of gravitational waves. However, because gravitational forces are more than 30 orders of magnitude weaker than electrostatic forces, the gravitational waves produced by a pendulum are far too weak to detect. Only extremely massive celestial bodies, such as black holes, generate gravitational waves strong enough to be observed by highly sensitive instruments like LIGO. Consequently, the motion of a pendulum is not strictly energy-conservative: as it emits gravitational radiation, its total energy gradually decreases. Nonetheless, this energy loss is far too small to be observable with current technology.

From Kinetic Energy to Other Forms

While **transimpacts** facilitate the buildup of kinetic energy within a system, it is evident that such accumulation cannot continue indefinitely. A complementary mechanism must therefore exist to convert kinetic energy into other forms—this process is referred to as **Impactrans**. During impactrans events, the motion or vibration of particles (such as molecules, atoms, or subatomic particles) leads to collisions mediated by electrostatic interactions. These interactions can intensify particle motion and, in some cases, excite electrons to higher orbitals or even eject them entirely, thereby altering the particle's potential energy. Moreover, the accelerated motion of electrons during such interactions can emit radiation. Thus, through impactrans, kinetic energy is transformed into both the potential and radiative forms, establishing the energy transformation pathways from kinetic to potential and radiative energy in the triangle of energy transformation.

The conversion of kinetic energy into radiative and potential energy through **impactrans** processes is evident in many everyday phenomena. A familiar example is the dent formed on a surface after being struck by a hammer. This deformation results from changes in the material's bond structures: some bonds are compressed, while others are stretched. The stretched bonds absorb a portion of the hammer's kinetic energy and store it as potential energy. Meanwhile, for the bonds that are compressed during deformation, part of the reduced potential energy is released as radiation in the form of impact heat and sparks.

Another familiar example is the warmth felt when rubbing one's palms together. This frictional heat arises from impactrans processes, where kinetic energy from macroscopic motion is transferred to microscopic particle interactions across rough surfaces. A similar mechanism explains the heat produced at the base of an air pump tube, where intensified molecular collisions increase the frequency of impactrans events. In the case of static electricity built up when rubbing a plastic rod with fur, electrons are dislodged from host atoms on the fur and accumulate on the rod—another manifestation of impactrans in action.

Summary

Through **Absorption**, **Emission**, **Conversion**, **Transimpact**, and **Impactrans**, energy can be transformed among three dynamic forms: radiative, potential, and kinetic. Collectively, these mechanisms facilitate the exchange of energy toward equilibrium, either within a single system or between different systems, thereby facilitating the **Zeroth Law of Thermodynamics**. While the preceding discussion primarily concerns interactions governed by Coulomb forces, analogous processes are expected under nuclear forces as well. In systems dominated by gravitational forces, some of these effects may be too weak to detect directly, but they should exist in principle.

Revision History

- 10/22/2025: Initial Post on Stanford Site
- 11/01/2025: Published on Zenodo
- 12/17/2025: Adding Links to Summaries of Related Articles
- 12/25/2025: Revised for Term Changes

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)
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