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APPLICATION OF GRAVITATIONAL WAVES IN THERMAL ELECTRICITY

P. Mallikharjuna Prasad
Department of Physics, Hindu College, Guntur, Andhra Pradesh, India

Abstract

Gravitational waves (GWs)—the ripples in spacetime predicted by Einstein's general relativity—have thus far provided powerful insights into cosmic phenomena. Recent explorations suggest GWs may induce thermal effects through energy dissipation mechanisms, with speculative potential for thermal-electric energy conversion at micro- or astrophysical scales. This review surveys theoretical models of GW–matter interaction, damping and heating in viscous media (e.g., accretion disks or fluid shells), experimental proposals for GW absorption by resonant devices, and concepts for using GW-induced thermal gradients or mechanical perturbations for electricity generation. Highlighting cutting-edge work from 2022 to 2025, this paper evaluates feasibility, discusses experimental constraints, and outlines future research opportunities linking gravitational physics and thermoelectric energy systems.

Keywords: gravitational waves; thermal effects; energy dissipation; thermoelectric conversion; GW–matter interaction; accretion heating; resonant absorbers.

1. Introduction

Gravitational waves (GWs), confirmed observationally by LIGO in 2015, have fundamentally extended our understanding of high-energy astrophysical events. Beyond their astronomical significance, GWs carry substantial energy that might—at least theoretically—be transferred to matter via absorption or damping processes. In this context, thermal electricity involves converting GW-induced heat or mechanical vibrations into electrical energy using thermoelectric or electromechanical systems.

While highly speculative, recent theoretical work has modeled GW damping in astrophysical media, and new proposals explore resonant superconducting or cavity-based detectors that may offer minimal energy absorption pathways. This review examines:

1. Theoretical modeling of GW dissipation and heating in viscous environments.
2. Experimental and conceptual schemes for direct GW energy absorption.

3. Conversion methods—principally thermoelectric or electromechanical—for transforming that absorbed energy into electricity.
4. Potential applications and challenges.

Focusing on literature from *2022–2025*, this review illuminates the current scientific landscape and outlines promising directions bridging gravitational physics with advanced energy technologies.

2. Theoretical Foundations: GW–Matter Interaction & Thermal Effects

2.1 Viscous Dissipation in Astrophysical Media

Gravitational waves propagating through viscous fluids or gaseous media can lose energy via viscous damping, leading to localized heating. For instance, Kakkat (2024) investigated GW heating in stationary accretion disks, demonstrating that GWs can impart thermal energy to disk material under realistic astrophysical conditions. Similarly, Bishop (2022, 2024) modeled wave propagation through viscous fluid shells, showing that damping mechanisms could elevate temperature in surrounding matter.While these effects are negligible at Earth-scale densities, in extreme environments near compact binaries or galactic nuclei, the heating could be non-trivial. Such studies provide a theoretical basis for GW-induced thermodynamics as a conceptual precursor to energy conversion.

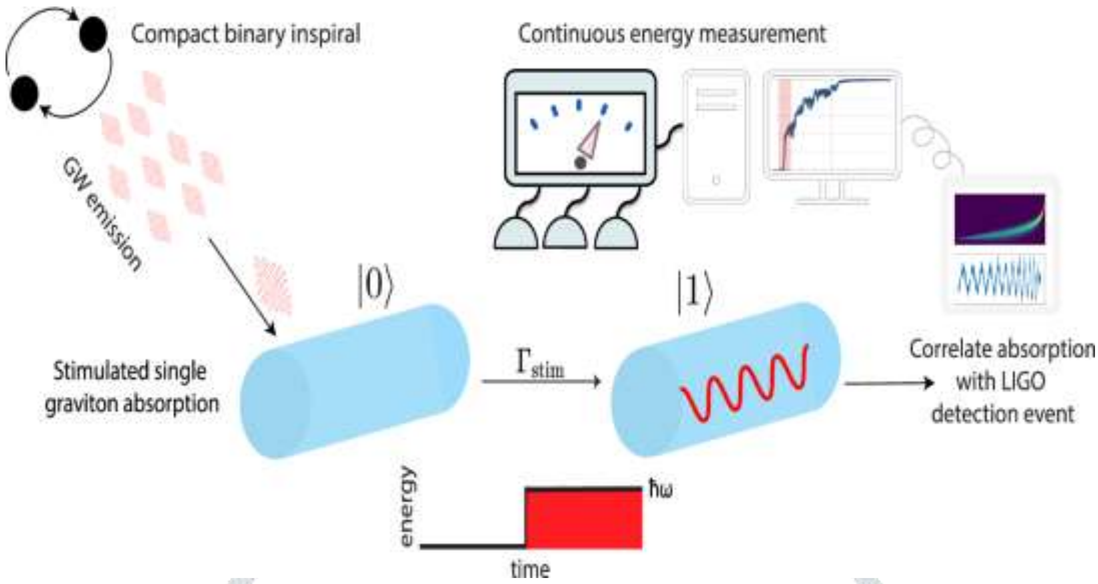
2.2 Fundamental Absorption Mechanisms

In ideal fluids, GWs pass with negligible absorption. However, real-world materials and structures—with internal friction, viscosity, or resonant modes—provide potential absorption channels. Charge carriers, magnetic domains, or superconducting states may interact with spacetime perturbations, offering pathways for energy transfer (though the efficiency remains speculative at best).**3. Experimental & Conceptual Schemes for GW Energy Absorption**

3.1 Resonant Cavities and Mechanical Detectors

Past GW detection efforts—like Weber bars—used resonant mass detectors to transduce passing GWs into mechanical vibrations. Although highly insensitive to energy retrieval, such concepts have inspired modern, compact designs. Carney et al. (2025) proposed a superconducting levitated sphere in a quadrupolar magnetic trap, which would convert GW stimulation into magnetic fluctuations. Navarro et al. (2024) examined cubic cavity resonators, especially in the microwave domain, as capable of interacting with high-frequency GWs.

Image 01: Mechanisms of Gravitational Wave–Matter Interaction Leading to Thermal and Electromechanical Effects



3.2 Electromagnetic Transduction via Gertsenshtein-Zel'dovich Effect

The Gertsenshtein effect describes the conversion between gravitational and electromagnetic waves in the presence of strong magnetic fields or plasma, offering a non-mechanical avenue for energy transfer. Kushwaha et al. (2024) proposed that this mechanism might underpin fast radio bursts (FRBs), hinting at astrophysical electromagnetic signatures arising from GW interactions. Berlin (2022) reviewed EM signal generation in resonant cavities induced by GWs—a potential pathway for converting spacetime perturbations directly into electromagnetic energy.

4. Toward GW-Induced Thermal Energy Conversion

In order for GW-induced heating or absorption to yield thermal electricity, a two-step mechanism is needed:

(i) Energy Absorption → thermal gradient or mechanical displacement, and
(ii) Conversion of that thermal/mechanical energy into electricity via thermoelectric, piezoelectric, or other transducers.

4.1 Thermoelectric Harvesting

No research to date explicitly connects GW-induced heating to thermoelectric generation. However, solid-state thermoelectric materials—when subjected to even minute temperature differentials—produce voltage via the Seebeck effect. If a resonant GW absorber (like a bar or cavity) could accumulate even minimal heating differentials, integration with TEGs (thermoelectric generators) could, in theory, produce electrical—albeit extremely low—power.

4.2 Piezoelectric and Electromechanical Transducers

Alternatively, mechanical vibrations from GW absorption could drive electromechanical energy conversion. Though not yet applied to GW scenarios, piezoelectrics (e.g., quartz, PZT) convert strain into electric charge. Early Weber detectors used piezo-ceramics for readout, pointing to a possible conceptual adaptation—harvesting GW-induced displacement to generate voltage.

5. Summary of Approaches:

Table 1.Mechanisms for GW Energy Absorption and Heating

Mechanism	Medium / Device	Energy Transfer Mode	Reference (Year)
Viscous damping in gas disks	Accretion disks	Viscous heating	Kakkat (2024)
Damping in viscous fluid shells	Fluid shells	Thermal absorption	Bishop (2022, 2024)
Superconducting resonator	Levitated sphere	Magnetic fluctuation energy	Carney et al. (2025)
Cavity resonator	Microwave cavity	EM excitation	Navarro et al. (2024)
Gertsenshtein conversion	Magnetic/plasma environments	Gravitational to EM waves	Kushwaha (2024); Berlin (2022)

Table 2. Conceptual Routes to Energy Harvesting from GW-induced Effects

Conversion Pathway	Transducer Type	Expected Output	Challenges
Thermal → Thermoelectric	Thermoelectric generators	Voltage/Power	Requires detectable thermal gradient
Mechanical → Piezoelectric	Piezoelectric materials	Charge/Vibration	GW strain amplitude extremely small
EM → Rectification	Antenna / EM detector	Electrical signal	EM conversion efficiency very low

6. Challenges, Feasibility & Future Directions

6.1 Extremely Weak Coupling and Energy Flux

GWs reaching Earth are extraordinarily weak—strain amplitudes of ~10^-21—corresponding to negligible energy transfer to macroscopic materials. Any heating or displacement is vanishingly small.

6.2 Detection vs. Harvesting

GW detectors like LIGO focus on detecting disturbances rather than extracting energy. Any attempt to harvest energy would greatly reduce sensitivity and is not aligned with current design principles.

6.3 Materials and Transducer Sensitivity

Designing materials with resonant enhancement or using quantum mechanical coupling (e.g., superconducting qubits) might amplify interaction. Carney et al.'s 2025 proposal offers a quantum-enabled magnetic transducer as a promising future direction .

6.4 Astrophysical-scale Implementation

On planetary scales—or around extremely massive or close binaries—GW heating could be meaningful. Research might explore whether GW-induced heating contributes to radiation from disks or stars, and whether that can be tapped by nearby spacecraft using thermoelectric collectors.

6.5 Interdisciplinary Innovation

Advances in quantum sensing, EM transduction, and thermoelectric materials could enable laboratory-scale demonstrations of GW-to-electricity conversion—even if only as proof-of-concept.

7. Conclusion

While fully realizing thermal-electric power generation from gravitational waves remains deeply speculative, recent theoretical and experimental proposals lay a nascent foundation. Viscous heating in astrophysical media and novel resonant detectors illustrate possible absorption mechanisms. Coupled with thermoelectric or electromechanical transducers, they offer a conceptual route to converting GW-induced thermal or mechanical energy into electricity.

Bridging gravitation, quantum sensing, and energy science will require breakthroughs in detector sensitivity and transducer efficiency. Even small-scale demonstration systems could greatly enrich our understanding of GW–matter coupling. As observational GW astronomy matures, it may inspire energy applications once deemed unattainable. The field remains in its conceptual infancy—but highly fertile for interdisciplinary inno

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