Introduction

Quantum energy teleportation begins with a question that sounds almost impossible:

Can a person extract energy from a distant quantum system by using only local quantum measurement, classical information, and pre-existing quantum correlations?

The answer, discovered and developed by Masahiro Hotta, is yes—but only in a very specific and carefully constrained sense. It is not science-fiction teleportation. It does not move a battery through space. It does not send energy faster than light. It does not violate conservation of energy. It does not allow free energy to be taken from the vacuum.

What it does show is subtler and more interesting: in quantum theory, energy, information, measurement, and entanglement are connected in ways that have no classical counterpart. A local measurement performed in one region can inject energy into a many-body quantum system. The measurement outcome can reveal information about distant quantum fluctuations. If that classical outcome is sent to a distant observer, the observer can perform a carefully chosen local operation that extracts energy from their region of the same quantum system. This is the basic idea of quantum energy teleportation, usually abbreviated QET (Hotta, 2008; Hotta, 2009; Hotta, 2011).

This book is about understanding that idea from the ground up.

We will not treat QET as a slogan. We will build the mathematics and physics step by step: quantum states, measurements, entanglement, Hamiltonians, locality, ground-state correlations, feedback operations, energy extraction, and realistic limitations. By the end, you should be able to read introductory research papers on QET, reproduce simple model calculations, and understand why the protocol is both surprising and consistent with ordinary quantum mechanics and relativity.

The central picture

Imagine a long chain of coupled quantum systems. For example, each site of the chain might be a spin-1/2 particle, also called a qubit. A qubit is the simplest quantum system: it has two basis states, often written as lvert 0⟩ and lvert 1⟩, but it can also exist in quantum superpositions of those states. Neighboring qubits in the chain interact with one another, so the energy of the whole chain is not just the sum of isolated qubit energies.

The total energy of such a system is described by an operator called the Hamiltonian, usually written as H. In quantum mechanics, an operator is a mathematical object that acts on quantum states. The Hamiltonian is the operator whose expectation value gives the average energy of a state, and it also determines how the state changes in time.

A system’s ground state is its lowest-energy state. If we choose the zero of energy conveniently, we may write

$$\langle g|H|g\rangle = 0,$$

where lvert g⟩ is the ground state. This does not mean the system is classically empty or inactive. In interacting quantum systems, the ground state can contain strong correlations between different regions. In quantum field theory, the vacuum also contains fluctuations and correlations; it is not a quiet classical nothingness.

Now place two observers near the chain.

Alice controls a small region A.

Bob controls a distant region B.

The QET protocol has three basic steps.

First, Alice performs a local measurement on region A. A local measurement is a measurement that acts only on a limited part of the total system. For example, Alice might measure whether her spin points mostly “up” or “down” along a chosen axis. Because measurement changes quantum states, Alice’s measurement generally disturbs the many-body ground state. This disturbance costs energy. In QET, Alice injects energy into the system.

Second, Alice sends her measurement outcome to Bob through an ordinary classical communication channel. This could be a light signal, an electrical signal, or any other classical message. The message carries information such as “my result was +” or “my result was -.” It does not carry the extracted energy itself.

Third, Bob performs a local operation on region B, chosen according to Alice’s message. If Alice reported +, Bob performs one operation. If Alice reported -, Bob performs another. Because the ground state contained correlations between regions A and B, Alice’s outcome gives Bob useful information about the quantum fluctuations near him. With that information, Bob can choose an operation that lowers the energy of the many-body system around B. The lost system energy appears as energy gained by Bob’s device.

That is QET in one paragraph.

But every sentence in that paragraph hides a serious concept. What exactly is a measurement? How does a measurement inject energy? What kind of correlation is useful? How can Bob extract energy from a region that was originally in the ground state? Why does this not allow faster-than-light signaling? Why does it not contradict the statement that the ground state is the lowest-energy state?

These questions are the reason this book exists.

Why the word “teleportation” appears

The word teleportation can be misleading if it is read too literally.

In ordinary language, teleportation suggests that an object disappears in one place and appears in another. That is not what happens here.

In quantum state teleportation, introduced by Bennett and collaborators in 1993, an unknown quantum state can be transferred from one system to another using shared entanglement and classical communication (Bennett et al., 1993). The original state is not copied; rather, the protocol uses measurement, entanglement, and a classical message to reproduce the state at a distant location. This is a major result in quantum information theory.

Quantum energy teleportation is related in spirit, but it is not the same protocol.

In QET, Alice does not teleport an unknown quantum state to Bob. Instead, Alice’s measurement obtains information about quantum correlations in a many-body system. Bob uses that information to extract energy locally. The “teleported” quantity is not a material object and not a quantum state. It is a usable energy gain at Bob’s location, made possible by information about distant correlations.

The name is justified because Bob’s energy extraction can occur without waiting for ordinary energy carriers from Alice’s region to physically propagate through the system, provided the classical communication reaches Bob first. In lattice systems, the speed at which disturbances spread is limited by locality bounds such as the Lieb-Robinson bound, which plays a role similar to an effective maximum signal velocity in many nonrelativistic quantum spin systems (Lieb and Robinson, 1972). QET respects such causal structure. Bob still needs Alice’s classical message, and that message cannot be sent faster than allowed by the physical communication channel.

So QET is not “energy sent faster than light.” It is better described as:

local energy extraction enabled by classical information about pre-existing quantum correlations, after energy has been injected elsewhere by measurement.

A first energy bookkeeping

Let us write the basic bookkeeping in a simple form.

Suppose the many-body system starts in its ground state lvert g⟩, and suppose we set the ground-state energy to zero:

$$\langle g|H|g\rangle = 0.$$

Alice performs a measurement. Her possible outcomes are labeled by μ. For example, μ might be +1 or -1. After Alice’s measurement, the average state of the system is no longer the original ground state. Its expected energy becomes

$$E_A > 0.$$

This E(A) is the energy injected by Alice’s measurement apparatus. The measurement is not free. Physically, Alice’s device interacts with the system, records an outcome, and disturbs the local quantum state.

Now Bob receives Alice’s outcome μ. Based on that outcome, he applies a local operation near region B. If this operation reduces the expected energy of the system by an amount E(B), then Bob’s apparatus can gain energy E(B).

In an idealized description, the final energy of the many-body system is

$$E_{\text{final}} = E_A - E_B.$$

Because the ground state has the lowest possible energy and was assigned energy zero, the final energy cannot be negative:

$$E_{\text{final}} \geq 0.$$

Therefore,

$$E_B \leq E_A.$$

This inequality expresses a simple but important point: Bob does not receive free energy from nothing. The total process remains consistent with energy conservation. Alice’s measurement injects energy; Bob’s conditional operation extracts part of the energy made available through the changed global state and the information Alice obtained.

However, this does not mean that energy simply traveled from Alice to Bob in the ordinary way. In QET, Bob’s local operation can create a region of reduced energy density near B, sometimes described as a region of negative energy density relative to the original ground-state energy distribution. The compensating positive energy remains elsewhere in the system. This structure is one of the reasons QET is connected to deeper topics such as passivity, vacuum fluctuations, and quantum energy inequalities.

Why measurement matters

In classical physics, measurement can often be imagined as passive. For example, if you look at a slow-moving ball with a camera, the ball’s motion is approximately unchanged. The measurement reveals information without significantly disturbing the object.

Quantum measurement is different. A quantum measurement is a physical interaction between the measured system and a measuring device. It can change the state being measured. This is not merely a technical inconvenience; it is one of the central features of quantum theory.

For example, suppose a qubit is in the superposition

$$\frac{1}{\sqrt{2}}(|0\rangle + |1\rangle).$$

If we measure it in the \lvert 0⟩, lvert 1⟩\ basis, we obtain either 0 or 1. After the measurement, the state is no longer the original superposition. It becomes the state corresponding to the observed outcome, at least in the ideal projective-measurement model commonly introduced in undergraduate quantum mechanics.

In a many-body system, this disturbance can affect energy. If the ground state depends on delicate correlations between neighboring regions, then a local measurement can break or modify those correlations. Since interaction energy often depends on correlations, changing them can raise the energy.

A useful analogy is a pair of coupled pendulums at rest in their lowest-energy coordinated motion. If you suddenly force one pendulum into a definite position, you may disturb the coordinated motion of the pair and inject mechanical energy. The quantum case is not exactly the same, because quantum measurement and entanglement have no perfect classical equivalent, but the analogy helps: disturbing a correlated low-energy state can cost energy.

QET uses this fact. Alice's measurement is not just a way to learn something. It is also an energetic action.

Why entanglement matters

A major resource in QET is entanglement.

Entanglement is a form of quantum correlation that cannot be explained by saying each subsystem simply had its own pre-existing state. For two systems A and B, an entangled state is one that cannot be written as an ordinary probabilistic mixture of independent states of A and B. We will define this precisely in Chapter 3.

For now, consider the two-qubit state

$$\frac{1}{\sqrt{2}}(|00\rangle + |11\rangle).$$

If Alice measures her qubit and obtains 0, Bob's qubit is correlated with that result. If Alice obtains 1, Bob's qubit is correlated differently. Yet Alice's measurement result is random, and Bob cannot know it unless Alice sends a classical message. This is the basic reason entanglement does not allow faster-than-light communication, a standard point in quantum information theory (Nielsen and Chuang, 2010).

In QET, the ground state of an interacting many-body system can be entangled across distant regions. Alice's local measurement outcome gives partial information about quantum fluctuations in Bob's region. Bob cannot access that information by local observation alone in the same useful way. But once Alice sends the outcome, Bob can condition his operation on it.

The word condition is important. A conditional operation is one whose form depends on received information. For example:

- If Alice reports $\mu = +1$, Bob rotates his spin slightly clockwise.
- If Alice reports $\mu = -1$, Bob rotates his spin slightly counterclockwise.

Either operation alone might not extract energy on average. The useful effect appears because Bob chooses the operation matched to Alice’s measurement result.

This is why QET belongs naturally to the world of quantum information. It is an energy protocol, but it is also a feedback protocol: measurement information guides a later operation.

Why the ground state is not an ordinary empty state

At first, QET may sound as if Bob extracts energy from the ground state. That would be impossible if interpreted too simply. The ground state is the lowest-energy state, so no operation on a closed system can lower its total energy below the ground-state value.

The resolution is that Bob is not acting on the undisturbed ground state with no extra information. Alice has already performed a measurement, and that measurement has changed the global state and injected energy. Bob acts after this change, using Alice’s classical outcome.

This connects to the concept of passivity. A passive state is a state from which no work can be extracted by a cyclic unitary operation, meaning an operation that changes the state and then returns the external control settings to their original form. Ground states are standard examples of passive states: if the system is already in its lowest-energy state, an ordinary global cyclic operation cannot extract work from it. The mathematical theory of passive states was developed by Pusz and Woronowicz and is part of the foundation of quantum thermodynamics (Pusz and Woronowicz, 1978).

QET does not contradict passivity. It uses a different situation:

1. Alice measures locally and injects energy.
2. Alice obtains information about correlations.
3. Bob uses that information to perform a conditional local operation.
4. The total energy bookkeeping remains nonnegative.

So QET is not a loophole in thermodynamics. It is a refined example of how measurement, information, and energy must be treated together.

A simple intuitive example

Before the full mathematics, let us imagine a two-spin system.

There are two coupled spins, one near Alice and one near Bob. Because they interact, the ground state is not simply “Alice’s spin has its own state and Bob’s spin has its own state.” Instead, the lowest-energy state may contain correlations between them.

Alice measures her spin. The result is random, but it is not useless. Because of the ground-state correlations, Alice’s result tells her something about how Bob’s spin is likely fluctuating. The measurement also disturbs the two-spin system and raises its average energy.

Alice sends one bit of information to Bob: perhaps + or -.

Bob then performs a small rotation on his spin. The direction of rotation depends on Alice’s bit. If the protocol has been designed correctly, Bob’s rotation reduces the expected energy of the two-spin system. The energy reduction appears as energy gained by Bob’s local device.

This example is intentionally incomplete. It does not yet specify the Hamiltonian, the ground state, the measurement operators, or Bob’s optimized unitary operation. Those details matter. Chapter 8 will work through a minimal two-spin model carefully, so that the words “extract energy” become an explicit calculation.

For now, the example gives the shape of the idea:

measurement creates both disturbance and information; correlation makes the information useful at a distance; conditional local control converts that information into local energy extraction.

What QET is not

Because QET is often misunderstood, it is useful to state several negative facts clearly.

QET is not ordinary energy transmission. In ordinary energy transmission, energy moves through a medium or field from source to receiver. For example, energy can move down a wire, through an electromagnetic wave, or along a spin chain as an excitation. In QET, Bob’s extraction is enabled by correlations and classical information, not by a packet of energy physically traveling from Alice to Bob in the ordinary sense.

QET is not faster-than-light signaling. Bob cannot choose to extract energy in a controlled way until he receives Alice’s classical message. If the message is limited by the speed of light, the protocol is also limited by that causal structure. In lattice systems, propagation is constrained by locality bounds such as the Lieb-Robinson bound (Lieb and Robinson, 1972).

QET is not a perpetual-motion machine. Alice’s measurement injects energy. Bob’s gain is bounded by the total energy available after Alice’s action. If all devices, memories, communication channels, and erasure costs are included, QET remains consistent with the second law of thermodynamics.

QET is not the same as quantum state teleportation. Quantum state teleportation transfers an unknown quantum state using entanglement and classical communication (Bennett et al., 1993). QET uses measurement information and correlations to permit local energy extraction.

QET is not science-fiction teleportation of matter. No object disappears at Alice’s location and appears at Bob’s location.

These distinctions are not meant to make QET less exciting. They make it more exciting, because the real phenomenon is subtle enough to survive serious physical constraints.

The path through this book

The book begins with conceptual foundations. Chapter 1 explains what QET is and is not in more detail. Chapters 2 and 3 build the quantum language of states, observables, measurements, density matrices, tensor products, reduced states, and entanglement. These are the tools needed to describe Alice’s measurement and Bob’s conditional operation.

Chapter 4 introduces energy in quantum mechanics through the Hamiltonian, ground states, time evolution, and local energy density. Chapter 5 discusses locality, causality, no-signaling, and Lieb-Robinson bounds. These topics are essential because QET lives exactly at the boundary between “surprising nonclassical correlation” and “no violation of causality.”

Chapters 6 and 7 explain the physical core: ground-state entanglement, vacuum fluctuations, and Hotta’s protocol. Chapter 8 then gives a minimal two-spin calculation, so that the protocol becomes concrete. Chapter 9 generalizes the mathematical structure using measurement operators and conditional operations.

The middle chapters study richer systems: spin chains, harmonic oscillator chains, continuous variables, and quantum fields. Later chapters connect QET to passivity, negative energy density, information theory, thermodynamics, open-system noise, experimental platforms, numerical methods, quantum networks, possible applications, and open problems.

The goal is not only to know that QET exists. The goal is to understand how it works.

How to think while reading

QET can feel paradoxical if you try to understand it with only classical habits. A productive way to read this book is to keep four questions active:

1. What is the quantum state before and after each operation?
2. Where is energy injected, and where is energy extracted?
3. What information is available locally, and what information requires classical communication?
4. Which physical law prevents an apparent paradox?

For example, when Alice measures, ask: what state changed? What energy changed? What information did she gain? When Bob acts, ask: why does his operation depend on Alice's outcome? What would happen if he did not receive the message? When the protocol seems to allow something strange, ask: where do no-signaling, energy conservation, and passivity enter?

This habit will turn QET from a mysterious phrase into a sequence of understandable physical steps.

Quantum energy teleportation is a young and still-developing subject. It touches quantum information, condensed matter physics, quantum field theory, and quantum thermodynamics. Its practical applications remain uncertain, and this book will treat them with caution. But as a theoretical idea, QET is already valuable: it teaches us that energy is not merely a local substance moving through space. In quantum theory, the ability to extract energy can depend on correlations, measurements, and information distributed across a system.

That is the journey ahead.

References

Bennett, C. H., Brassard, G., Crépeau, C., Jozsa, R., Peres, A., and Wootters, W. K. (1993). “Teleporting an unknown quantum state via dual classical and Einstein-Podolsky-Rosen channels.” Physical Review Letters, 70, 1895–1899.

Hotta, M. (2008). “A protocol for quantum energy distribution.” Physics Letters A, 372(35), 5671–5676.

Hotta, M. (2009). “Quantum Energy Teleportation in Spin Chain Systems.” Journal of the Physical Society of Japan, 78, 034001.

Hotta, M. (2011). “Quantum Energy Teleportation: An Introductory Review.” arXiv:1101.3954.

Lieb, E. H., and Robinson, D. W. (1972). “The finite group velocity of quantum spin systems.” Communications in Mathematical Physics, 28, 251–257.

Nielsen, M. A., and Chuang, I. L. (2010). Quantum Computation and Quantum Information: 10th Anniversary Edition. Cambridge University Press.

Pusz, W., and Woronowicz, S. L. (1978). “Passive states and KMS states for general quantum systems.” Communications in Mathematical Physics, 58, 273–290.

Document information

Introduction

Project	Quantum Energy Teleportation
Document	Document 1.4
Author	mujirin
Verifier	Not verified
Downloaded	July 07, 2026 07:10 KST
Status	Working
Document link	https://theorytrace.com/projects/quantum-energy-teleportation/documents/introduction/