Chapter 1: What Quantum Energy Teleportation Is—and Is Not

Quantum energy teleportation, usually abbreviated QET, is a real idea in quantum physics, but its name can easily mislead us. The word teleportation makes it sound as if a chunk of energy disappears from one place and appears in another place, like an object in science fiction. That is not what happens.

A better first sentence is this:

Quantum energy teleportation is a protocol in which a distant observer can extract energy from a local part of a quantum many-body system by using classical information obtained from a local measurement performed elsewhere.

This sentence contains several important words, so let us slow down.

A protocol is a planned sequence of physical actions. In QET, the sequence is usually described using two parties, traditionally called Alice and Bob. Alice acts on one region of a quantum system. Bob acts on another region, far away from Alice. A quantum many-body system is a system made of many interacting quantum parts: for example, a chain of spins, a set of coupled oscillators, or a quantum field. A local measurement is a measurement performed only on a small region of the system. Classical information means ordinary information, such as a bit value 0 or 1, that can be sent through an ordinary communication channel. It is not itself a quantum state.

The surprising claim of QET is that Alice's local measurement can give information about quantum fluctuations near Bob. If Alice sends her measurement result to Bob, Bob can choose a suitable local operation and extract energy from his region. This idea was introduced and developed by Masahiro Hotta in spin-chain and quantum-field settings (Hotta, 2008; Hotta, 2009; Hotta, 2011).

At first, this may sound impossible. If Bob extracts energy at his location, where did that energy come from? If Alice and Bob are far apart, did energy travel instantly? If the system began in its lowest-energy state, how can anyone take energy from it?

These are exactly the right questions. This chapter answers them at the conceptual level. Later chapters will build the mathematics carefully.

1.1 The central physical picture

Imagine a long chain of quantum spins. A spin is a simple quantum degree of freedom that can behave somewhat like a tiny magnetic needle, although it does not literally point in a definite classical direction before measurement. Neighboring spins interact, so the chain is not just a collection of independent pieces.

Suppose the whole chain is prepared in its ground state. The ground state is the state with the lowest possible energy for the full system. If the Hamiltonian is the operator representing the total energy, then the ground state is an energy-minimizing state of that Hamiltonian. We will study Hamiltonians in detail in Chapter 4.

Now place Alice near the left side of the chain and Bob near the right side.

The basic QET sequence is:

1. The chain begins in its ground state.
2. Alice performs a local measurement on her part of the chain.
3. This measurement usually injects energy into the chain.
4. Alice sends the measurement result to Bob through a classical channel.
5. Bob performs a local operation chosen according to Alice's result.
6. Bob's operation can reduce the energy of the chain near him, allowing Bob's apparatus to gain energy.

The important point is that Bob's operation is conditional. This means that Bob does not always do the same thing. He chooses what to do depending on Alice's message. If Alice gets result "0," Bob may apply one operation. If Alice gets result "1," Bob may apply another.

For example, in a simple two-outcome version:

$$\text{Alice measures and obtains } \mu \in \{0, 1\}.$$

She sends μ to Bob. Bob then applies a local unitary operation Uμ, where the operation depends on μ. A unitary operation is a reversible quantum operation. It is represented mathematically by an operator U satisfying

$$U^\dagger U = UU^\dagger = I,$$

where U^† is the adjoint of U, and I is the identity operator.

The protocol is designed so that Bob’s operation lowers the system’s energy by an amount $E_{(B)} > 0$. If Bob’s device is arranged to capture this energy, then Bob has extracted energy from his local region.

This is the basic phenomenon: measurement information from Alice enables energy extraction by Bob.

1.2 A first energy balance

Let us choose the zero of energy so that the initial ground-state energy is

$$E_{\text{ground}} = 0.$$

This is only a choice of reference. In physics, we often choose a convenient zero point for energy, just as we may choose sea level as zero height.

Before Alice does anything, the expected energy of the system is

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

Here H is the Hamiltonian, and $\langle H \rangle$ means the expectation value of energy.

After Alice performs her local measurement, the system is generally disturbed. This disturbance costs energy. On average, Alice injects an amount

$$E_A > 0.$$

So after Alice’s measurement, the system has expected energy

$$\langle H \rangle = E_A.$$

Then Alice sends her classical measurement result to Bob. The message itself may require physical energy to send in a real laboratory, but that is not the energy counted as the “teleported” energy in the ideal QET protocol. The role of the message is informational: it tells Bob which operation to perform.

After Bob performs the correct conditional local operation, he extracts an amount of energy

$$E_B > 0.$$

The system's expected energy becomes

$$\langle H \rangle = E_A - E_B.$$

Since the original ground state had the lowest possible total energy and we chose its energy to be zero, the final expected energy cannot be negative:

$$E_A - E_B \geq 0.$$

Therefore,

$$E_B \leq E_A.$$

This simple inequality is already very important. It tells us that QET is not a free-energy machine. Bob cannot extract more total energy than Alice injected, at least when the initial state is the ground state and the full accounting is done correctly. This is consistent with the passivity of ground and thermal equilibrium states, a principle developed in rigorous quantum thermodynamics by Pusz and Woronowicz and by Lenard (Pusz and Woronowicz, 1978; Lenard, 1978).

So why is QET interesting?

Because Bob may extract energy before any ordinary energy-carrying excitation from Alice's region has had time to reach Bob's region. In lattice systems, the influence of local disturbances is limited by an effective maximum velocity described by Lieb-Robinson bounds (Lieb and Robinson, 1972). QET does not break this bound, because Bob still needs Alice's classical message. But it can separate energy extraction from ordinary energy transport through the material.

This is one of the key surprises.

1.3 The resource: correlations in the ground state

Classically, we often imagine a lowest-energy state as quiet and empty. If a classical system is in its lowest-energy configuration, there seems to be nothing useful to learn by measuring one part of it. But quantum ground states are different.

A quantum ground state of an interacting many-body system can contain correlations between distant regions. A correlation means that information about one part gives statistical information about another part.

For example, suppose Alice and Bob each have a coin. If the coins are independent, then learning Alice’s coin result tells us nothing about Bob’s. But if the coins were prepared so that they always match, then learning Alice’s result tells us Bob’s result. That is a classical correlation.

Quantum systems can have stronger and subtler correlations. In particular, they can be entangled. Entanglement is a kind of quantum correlation that cannot be explained by saying each part simply carried pre-existing local properties. We will study this carefully in Chapter 3. For now, the important idea is:

The ground state of an interacting quantum system can contain nonlocal correlations even when no signal is being sent.

QET uses these correlations.

Alice’s local measurement does two things at once. First, it disturbs the system and injects energy. Second, its outcome gives Alice information about fluctuations that are correlated with Bob’s region. A fluctuation is a deviation from a simple average value. In quantum theory, even a ground state can have fluctuations in local observables, because not all physical quantities can have sharp definite values at the same time.

Bob uses Alice’s information to choose an operation that is well matched to the local fluctuation near him. With the right choice, Bob can extract energy from his region.

An analogy may help, but it must be used carefully.

Imagine two distant buoys on a strange quantum sea. Alice cannot send a wave instantly to Bob. But the sea has pre-existing correlated ripples. By measuring her buoy, Alice learns something about the ripple pattern near Bob. She sends Bob a message: “push now in this direction.” Bob uses that timing information to extract energy locally. The energy he extracts is not carried by Alice’s message. The message only tells him how to act.

The analogy is imperfect because quantum correlations are not just hidden classical waves. Still, it captures the basic structure: pre-existing correlations plus local feedback can enable local energy extraction.

1.4 Why Alice's measurement injects energy

Measurement in quantum mechanics is not merely passive observation. A measurement can change the state of the system being measured.

For example, suppose a spin is not in a definite “up” or “down” state along the z-axis. If Alice measures its z-component, the spin state after the measurement is changed into a state compatible with the observed result. This change can disturb quantities that do not commute with the measured observable.

Two observables commute if their operators satisfy

$$AB = BA.$$

If they do not commute, then measuring one can disturb the other. Energy is represented by the Hamiltonian H. If Alice measures a local observable $M_{(A)}$, and $M_{(A)}$ does not commute with the Hamiltonian,

$$[M_A, H] = M_A H - H M_A \neq 0,$$

then Alice's measurement can change the system's energy.

This is why QET usually begins with an energy cost. Alice's measurement is not free. It injects energy into the many-body system. Hotta's QET protocols explicitly account for this energy injection before Bob's energy extraction (Hotta, 2008; Hotta, 2009).

A simple example:

- A spin chain is in its ground state.
- Alice measures one spin in a direction that is not aligned with the energy-minimizing structure of the chain.
- The measurement destroys part of the local quantum coherence.
- The post-measurement state is no longer the ground state.
- Therefore, the system's expected energy increases.

This measurement-induced energy increase is essential. Without it, QET would look like energy extraction from a ground state without compensation, which would contradict ordinary energy principles.

1.5 What Bob actually extracts

When we say “Bob extracts energy,” we mean something precise.

Bob performs a local operation on his part of the quantum system. During this operation, Bob’s external device interacts with the system. If the system’s energy decreases by E(B), then Bob’s device can gain energy E(B), assuming the operation is implemented in an energy-conserving way including the device.

So Bob is not creating energy. He is transferring energy from the quantum system to his apparatus.

But how can the system near Bob lose energy if the total system started in its ground state?

The answer is that after Alice’s measurement, the total system is no longer in the ground state. Alice has injected energy. Bob’s conditional operation can create a region near him whose local energy is lower than the ground-state local reference. This is often described as creating a region of negative local energy density relative to the chosen ground-state baseline.

This phrase needs care.

A local energy density is a way of assigning energy to regions of space or to sites of a lattice. In many quantum systems, local pieces of the energy can have expectation values below their ground-state local reference, even though the total energy remains nonnegative. Negative local energy does not mean the whole system has negative energy. It means that one region is below the reference level, while other regions compensate with positive energy.

In QET:

- Alice’s region receives positive energy from the measurement.
- Bob’s operation can produce a local negative-energy region near Bob.
- Bob’s apparatus gains positive energy.
- The total energy balance remains consistent.

This is one reason QET is subtle. The global ground state is stable, but local energy densities can be rearranged in ways that are not obvious from classical intuition.

1.6 QET is not ordinary quantum teleportation

Quantum energy teleportation is related in spirit to quantum information, but it is not the same as ordinary quantum teleportation.

Ordinary quantum teleportation was introduced by Bennett, Brassard, Crépeau, Jozsa, Peres, and Wootters in 1993 (Bennett et al., 1993). In that protocol, Alice transfers an unknown quantum state to Bob using two resources:

1. a shared entangled state, and
2. a classical message from Alice to Bob.

The original quantum state at Alice’s location is destroyed, and Bob reconstructs it at his location after receiving Alice’s classical information. No faster-than-light communication occurs, because Bob cannot complete the reconstruction before the classical message arrives. This is a standard result in quantum information theory (Nielsen and Chuang, 2010).

QET has a different goal.

Ordinary quantum teleportation transfers a quantum state. QET enables extraction of energy from a distant part of a many-body system. In QET, Bob is not reconstructing Alice’s quantum state. Instead, he is using Alice’s measurement result as feedback information for a local energy-extraction operation.

The similarity is structural:

- both use quantum correlations,
- both require classical communication,
- both forbid faster-than-light signaling.

But the physical tasks are different.

Ordinary quantum teleportation asks:

> Can Bob reproduce an unknown quantum state originally held by Alice?

QET asks:

> Can Bob extract energy locally by using information obtained from Alice’s local measurement?

The answer to both questions is yes, but for different reasons and with different physical meanings.

1.7 QET is not faster-than-light signaling

QET does not allow Alice to send a message to Bob faster than light.

This is crucial.

In quantum theory, entanglement can create correlations between distant measurement outcomes. However, correlations alone do not allow controllable communication. Bob cannot look only at his local system and determine what Alice measured, which outcome Alice obtained, or whether Alice chose to send a useful message. The classical message is necessary.

This principle is called no-signaling. It means that local quantum operations performed by Alice cannot be used by Bob to receive information instantly at a distance. No-signaling is a standard consequence of the mathematical structure of quantum operations and measurements (Nielsen and Chuang, 2010).

In QET, Bob’s local operation must depend on Alice’s measurement outcome. If Bob does not know Alice’s outcome, he cannot choose the correct conditional operation. If he guesses, the average result does not produce the intended energy gain.

So the timeline matters:

1. Alice measures.
2. Alice obtains a classical result.
3. Alice sends that result through an ordinary channel.
4. Bob receives the result.
5. Bob performs the corresponding operation.

The classical message cannot travel faster than light. Therefore, QET cannot send usable information faster than light.

In a spin chain or condensed-matter system, there is another useful comparison. Ordinary energy-carrying excitations often move through the material at some finite speed. In many lattice systems, Lieb-Robinson bounds give an effective limit on how quickly local disturbances can spread (Lieb and Robinson, 1972). QET can allow Bob to extract energy before Alice’s injected energy arrives through the material, but not before Alice’s classical message arrives.

Thus QET can be faster than ordinary energy transport through a medium in a limited operational sense, but it is not faster than light and not faster than communication.

1.8 QET is not energy transport in the usual sense

In ordinary energy transport, energy moves through space by a physical carrier.

Examples:

- Heat flows through a metal.
- An electromagnetic wave carries energy from an antenna to a receiver.
- A phonon carries vibrational energy through a crystal.
- A spin excitation carries energy along a magnetic chain.

In all these cases, energy travels from one region to another through local physical interactions.

QET is different. In the ideal protocol, the energy Bob extracts is not the same energy packet that Alice injected traveling across the system. Alice’s measurement injects energy into her region. Bob extracts energy from his region by using information about correlations already present in the initial state.

This is why the word “teleportation” appears: the usable energy appears at Bob’s side without an ordinary energy carrier traveling from Alice to Bob during the relevant time interval.

But we must immediately add the correction:

QET does not teleport energy as a substance. It teleports the ability to extract energy, using classical information and quantum correlations.

That phrase is more accurate.

Bob's extracted energy comes from the local quantum system with which he interacts. The possibility of extracting it is unlocked by Alice's information. The total energy budget is paid by Alice's measurement disturbance and by the full physical implementation of the protocol.

1.9 QET is not science-fiction teleportation

Science-fiction teleportation usually means moving an object, a person, or a body from one place to another without crossing the space between. QET does not do anything like that.

It does not move matter.

It does not move a battery.

It does not move a particle from Alice to Bob.

It does not move Alice's local energy packet intact to Bob.

It does not allow Bob to receive energy without a physical system being present at his location.

Bob must already have access to part of a shared quantum system. Alice and Bob are not acting on empty space in an ordinary classical sense. They are acting on different regions of one quantum system whose state contains correlations.

A useful way to say this is:

QET is not teleportation of stuff. It is a feedback-controlled energy extraction protocol enabled by quantum correlations.

This may sound less dramatic, but it is much more interesting scientifically.

1.10 Why the ground state is not simply "empty"

QET often begins with a system in its ground state. If the ground state has the lowest possible energy, why is anything extractable?

The answer is subtle: Bob cannot simply extract energy from the ground state by acting locally without Alice's measurement information. If that were possible, the ground state would not be stable in the relevant thermodynamic sense. Ground states and thermal equilibrium states are connected to the idea of passivity, meaning that no work can be extracted from them by suitable cyclic operations under the assumptions of the passivity theorem (Pusz and Woronowicz, 1978; Lenard, 1978).

But QET is not simply "Bob acts on the ground state." The full protocol includes Alice's measurement. Alice changes the global state and injects energy. Her measurement outcome contains information correlated with Bob's region. Bob uses that information to perform a conditional operation.

So the ground state is not a battery waiting to be drained. Rather, it is a correlated quantum state. Alice's measurement converts some of those correlations into usable classical information, while also injecting energy. Bob's feedback operation uses the information to extract energy locally.

The ground state is passive globally, but it can still contain nonlocal correlations that make QET possible after a measurement-and-communication protocol.

1.11 A simple story version

Let us now tell the whole idea in one coherent story.

Alice and Bob share a long quantum spin chain prepared in its ground state. The chain has no available global energy in the ordinary sense: its total energy is already minimal. However, because the spins interact, the ground state contains quantum correlations between distant regions.

Alice measures a spin near her. This measurement disturbs the chain and injects energy $E_{(A)}$. The outcome of the measurement gives Alice partial information about correlated quantum fluctuations elsewhere in the chain, including near Bob.

Alice sends her outcome to Bob as an ordinary classical message. The message might be one bit, such as "0" or "1." It travels no faster than light.

Bob receives the message. Depending on Alice's result, he applies one of several possible local operations to his part of the chain. Because the operation is chosen using Alice's information, it can reduce the local energy of the chain near Bob. Bob's apparatus gains energy $E_{(B)}$.

The final total energy of the chain is still nonnegative:

$$E_A - E_B \geq 0.$$

No conservation law is broken. No signal travels faster than light. No matter is teleported. The extracted energy is local to Bob's region, and the ability to extract it came from Alice's measurement information combined with pre-existing quantum correlations.

That is quantum energy teleportation.

1.12 What we should expect from the rest of the book

This chapter has given the conceptual outline. The later chapters will turn each part into precise mathematics and physics.

We will need to understand:

- what quantum states are,
- how measurements change states,
- how composite systems are described,
- what entanglement and correlations mean,
- how Hamiltonians define energy,
- how locality and causality constrain operations,
- how ground-state fluctuations can store useful correlation structure,
- how Alice's measurement injects energy,
- how Bob's conditional operation extracts energy,
- how much energy can be extracted in specific models,
- and how QET might be implemented or tested experimentally.

The most important attitude is caution. QET is real quantum physics, but it is not magic. Its power comes from the exact rules of quantum measurement, entanglement, feedback, and energy conservation. If any of those pieces is misunderstood, QET begins to sound impossible or mystical. If they are understood carefully, QET becomes a beautiful example of how information and energy are connected in quantum theory.

For now, remember the central sentence:

Quantum energy teleportation is the extraction of energy at one location by using classical information obtained from a distant local quantum measurement on a correlated quantum system.

Everything that follows will make this sentence precise.

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