

# The Laws of Thermodynamics and Information and Economics

By:

William Antonio Boyle, PhD

Prince George's Community College  
Largo, Maryland, USA

15 October 2019

# Thermodynamics

- Began as the study of steam engines, that is, the production of motion from heat.
- Name, from the Greek;  
Therme = Heat, Dynamis = Power
- The basic laws of thermodynamics were developed between 1850 and 1860, based primarily on the works of James Joule, Rudolf Clausius, William Rankine, and William Thomson (Lord Kelvin).

# Thermodynamics

- In general, thermodynamics studies the transformation of energy of different types (e.g., thermal, solar, mechanical, chemical, electrical, kinetic, potential, etc.) from one kind to another.
- Any transformation of energy must conform to certain universal restrictions, known as the first and second laws of thermodynamics.
- A scientific law is an expression of an observed regularity of nature, i.e., it is simply a summary of observations of a certain kind of natural phenomena.
- No exceptions have ever been found to the laws of thermodynamics.

# Thermodynamics

- At the present time, thermodynamics is considered fundamental for the study of:
  - Chemistry and physics
  - Biology and ecology
- Thermodynamics can also be considered of primary importance for the study of:
  - Information theory
  - Economics

## The First Law of Thermodynamics

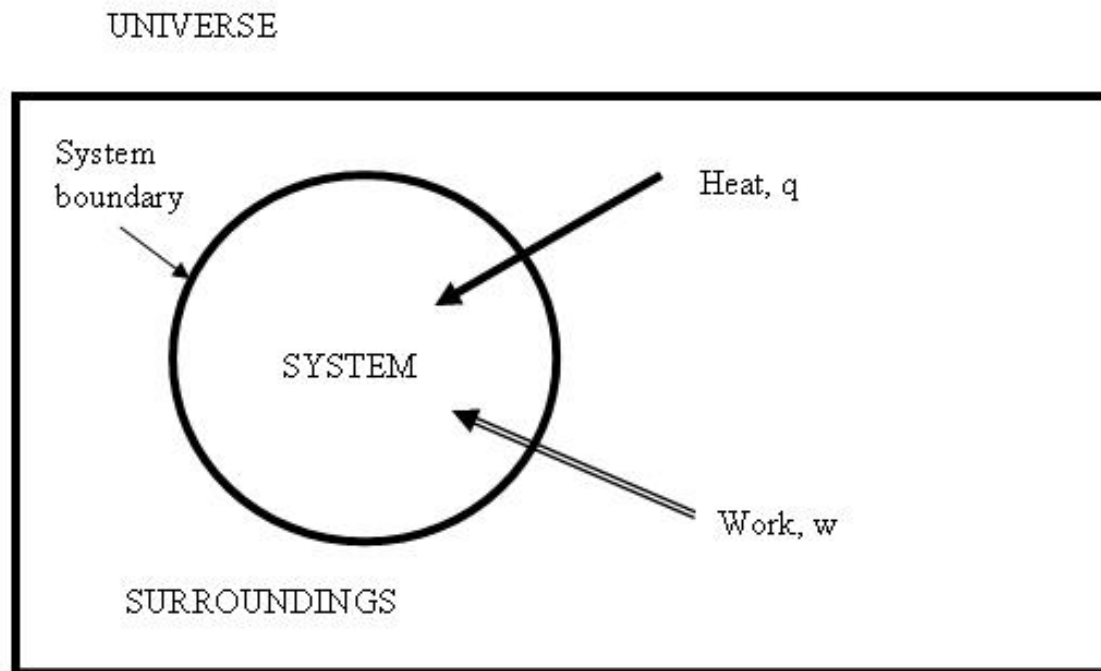
The **first law** is very simple and is known as the "Law of conservation of energy"

This law states that "Energy cannot be created or destroyed but can only be transformed."

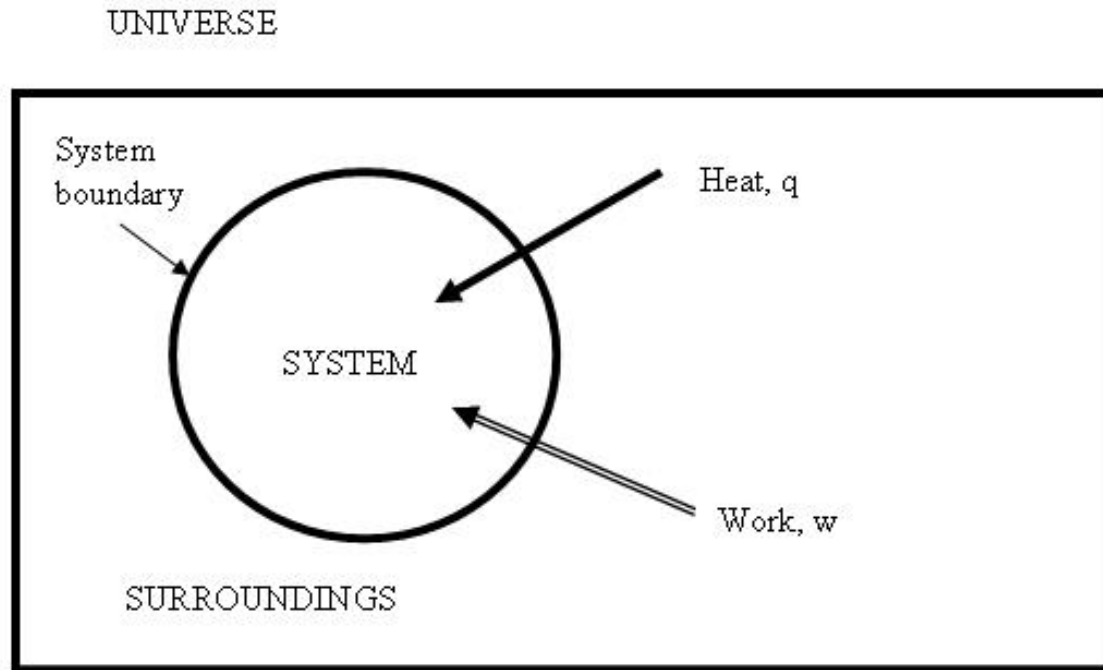
What this means is that for **any** process in which energy is involved, when one adds up all the quantities of the different forms of energy at the end, this sum has to be equal to the total amount of energy that was present at the beginning of the process, no more, and no less.

## The First Law of Thermodynamics

The **first law** is valid for the Universe = System + Surroundings



## The First Law of Thermodynamics



$$\Delta E_{\text{universe}} = 0 \quad (\text{Always!})$$

$$\Delta E_{\text{system}} = q + w ; \text{ where } \Delta E_{\text{system}} = (E_{\text{final}} - E_{\text{initial}})$$

## The First Law of Thermodynamics

Heat and work are transfers of energy that only exist while crossing the system boundary.

Heat,  $q$ , is energy transferred through the system boundary due to a difference in temperature. Heat is usually (but not always) observed as a change in temperature of a material.

Work,  $w$ , is energy that is transferred through the system boundary that is not heat. Work is usually (but not always) observed as the macroscopic movement of mass.

## The First Law of Thermodynamics

Units of energy:

The Joule,  $J = (1 \text{ Newton}) \times (1 \text{ meter})$

The calorie, cal = The amount of energy that will raise the temperature of one gram of water by  $1^\circ\text{C}$

$$1 \text{ cal} = 4.184 \text{ Joules}$$

Note:

$$1 \text{ Nutritional Calorie} = 1000 \text{ cal} = 1 \text{ kcal}$$

## The First Law of Thermodynamics

Heat and work are transfers of energy that only exist while crossing the system boundary.

Heat,  $q$ , is energy transferred through the system boundary due to a difference in temperature. Heat is usually observed as a change in temperature of a material.

Work,  $w$ , is energy that is transferred through the system boundary that is not heat. Work is usually observed as the macroscopic movement of mass.

**Energy** can be defined as "the movement of mass on a microscopic or a macroscopic scale, or the capacity to cause such movement" ([Planck 1903, p. 39](#)) and the first law simply states that the quantity of energy must be conserved.

Movement of mass = Macroscopic kinetic energy, microscopic thermal energy.

Capacity to cause movement of mass = Macroscopic potential energy, microscopic chemical or nuclear energy.

## The First Law of Thermodynamics

The previous Planck definition for **Energy** avoids the problems with the two commonly accepted definitions for this concept.

The problem with the "Traditional" definition, i.e., "Energy is the capacity to perform work or release heat," is that it is FALSE.

This should be obvious after a moment's reflection: Once the energy in a gallon of gasoline purchased at the gas station, or the energy in a kilowatt-hour of electrical energy purchased from the utility company has been used, it is NO longer capable of producing work or releasing heat. The same is true for energy from *any* source.

As this traditional definition is obviously false, since the 1960s the Physics community has adopted this "Non-definition" for **Energy**: "There is NO general definition for energy. Only specific forms of energy can be defined."

The problem with the Physics "Non-definition" is that it is logically inconsistent: If there is NO general definition for energy, that means that the different forms of energy have NOTHING in common, and if they have NOTHING in common, how can they all be the same thing, **Energy**?

## The Second Law of Thermodynamics

**The Second Law of Thermodynamics** is based on the simple fact that in nature heat always flows from a hot body to a cold body and never in the inverse direction.

The **second**, or **entropy law**, places a restriction on the kinds of energy transformation that can take place.

One consequence of this second law is that there is a quality of energy that places a limit on the transformation of that energy into useful work.

Energy of the movement of a macroscopic mass (kinetic energy) or any energy which can be transformed into movement of a macroscopic body or mass is **usable** energy, and is called free energy and can be transformed into useful work (That is, it is “free” to be transformed into work).

On the other hand, if the energy cannot be transformed into movement of a macroscopic body or mass, it is **unusable** energy, and it is called bound energy and cannot be transformed into work.

## The Second Law of Thermodynamics

For any given system, the least usable energy is thermal energy at the temperature of the environment; this energy cannot be transformed into useful work at all.

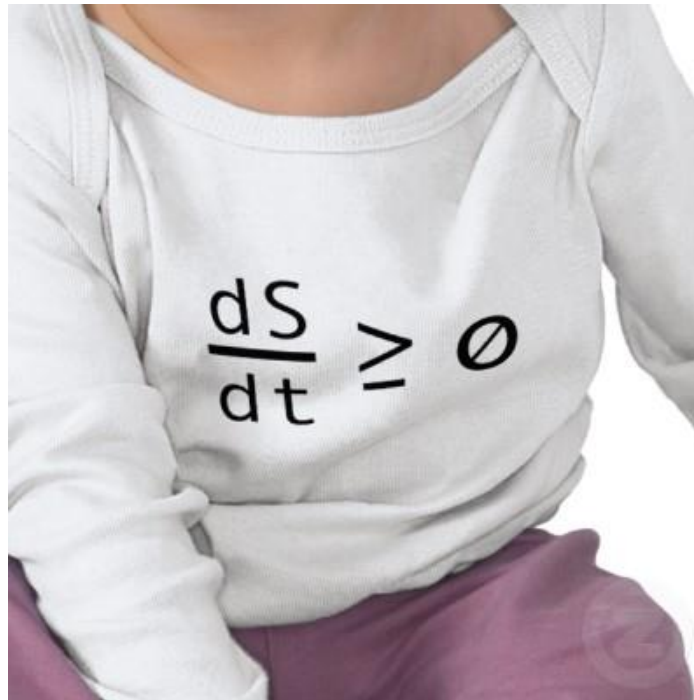
On the other hand, high-temperature thermal energy is largely usable and very versatile (for example, solar energy).

## The Second Law of Thermodynamics

The **Second Law of Thermodynamics** can be stated as, "The entropy of the universe (or of any isolated system) can never decrease."

The **entropy, S**, is a measure of the disorder or disorganization of a system.

The second law is also valid for the Universe = System + Surroundings



## The Second Law of Thermodynamics

Another statement of the **Second Law** is, "A process whose only effect is a local lowering of entropy cannot exist."

This means that a local lowering of entropy can occur, but only if there is a larger increase of entropy elsewhere, so that the net overall effect is an increase in entropy.

So, the entropy of a particular system can be reduced, but only if the entropy of the surroundings is increased by a larger amount, so that overall, the entropy of the universe is increased.

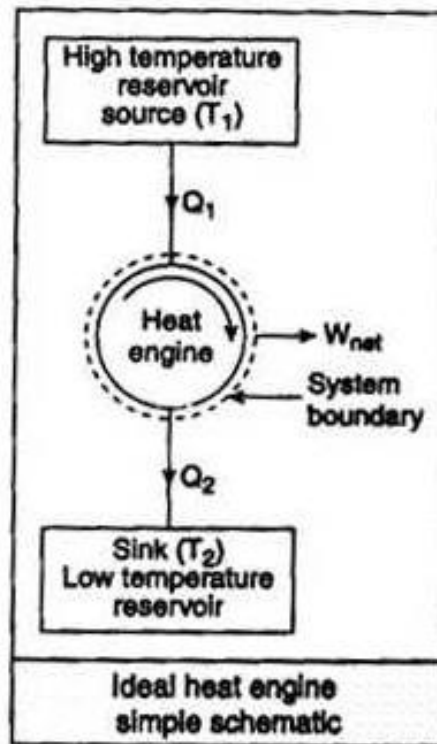
All this means that to produce work, **usable** energy must be consumed and transformed into **unusable** energy, i.e., thermal energy at the temperature of the environment.

This also means that usable energy is **not** recyclable, because each amount can be used to produce work essentially only once (Yes, energy can be re-used, but only the part that has not degraded to unusable energy).

## The Laws of Thermodynamics

These concepts may be visualized in the operation of a heat engine (a simplified conceptual model of a steam engine).

This is a machine that turns heat into work; it needs a source of high-temperature heat (**usable** energy) and a "sink" (a repository) for the discarded low-temperature heat (**unusable** energy).



## The Laws of Thermodynamics

The first law tells us that the quantity of high-temperature heat (thermal energy) that is consumed is equal to the sum of the quantity of work produced plus that of the discarded low-temperature heat: the total amount of energy is conserved.

$$Q_1 = W_{\text{net}} + Q_2$$

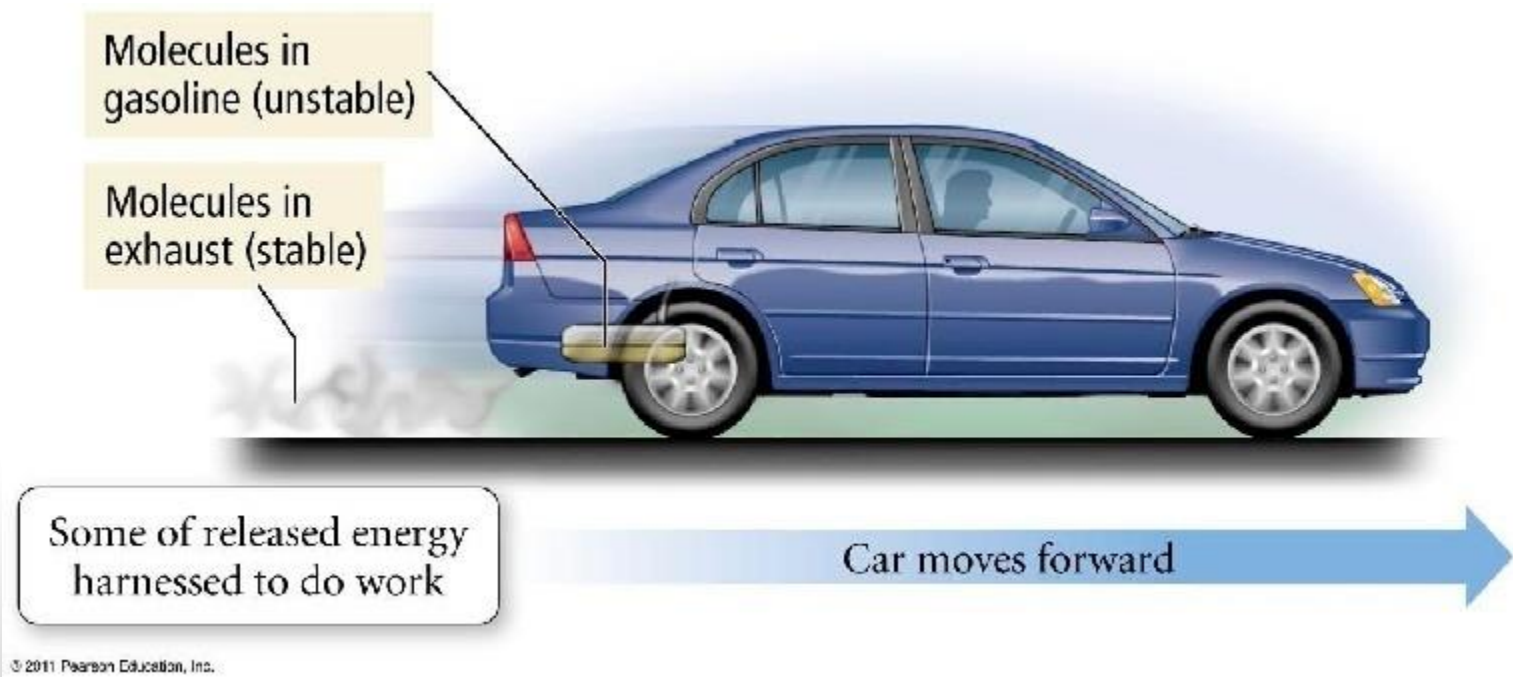
The second law tells us that the net entropy has to increase, i.e., that the engine has to produce waste heat - or else the engine won't work; and it tells us that **usable** energy is transformed into **unusable** energy.

$$\Delta S_{\text{UNIVERSE}} \geq 0$$

## The Laws of Thermodynamics

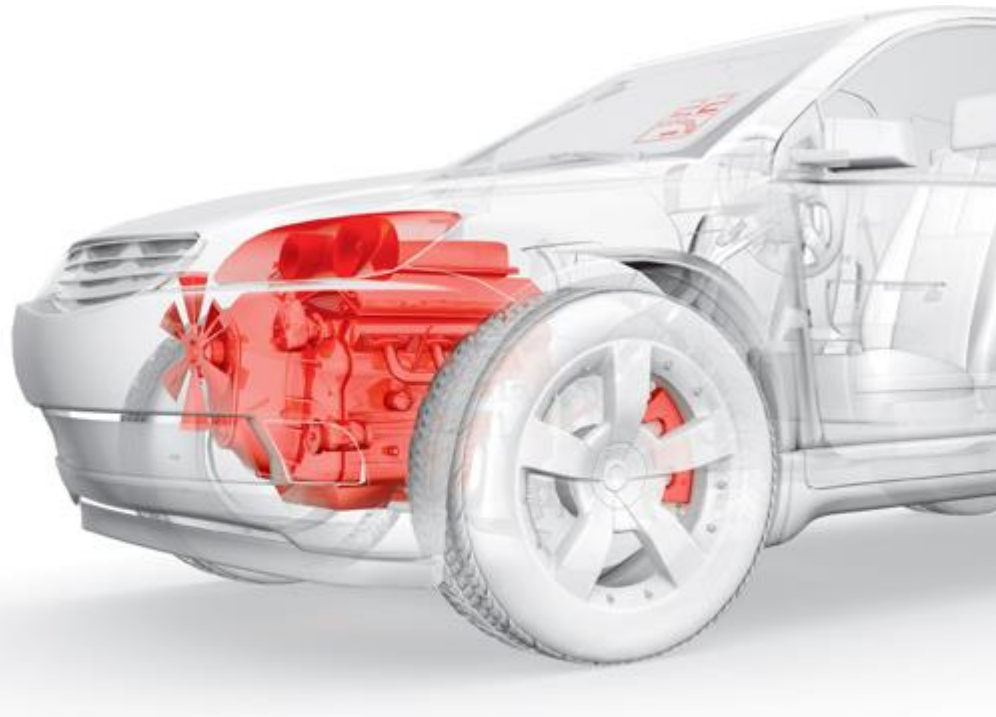
This is how a car or automobile operates. It takes the energy in the molecules of gasoline and turns it into macroscopic kinetic energy of the entire car.

Some of the energy originally in the gasoline is released as thermal energy and leaves through the exhaust pipe.



## The Laws of Thermodynamics

The car engine is a special mechanism that transforms the **usable** chemical energy in the gasoline into the work of the car moving forward.

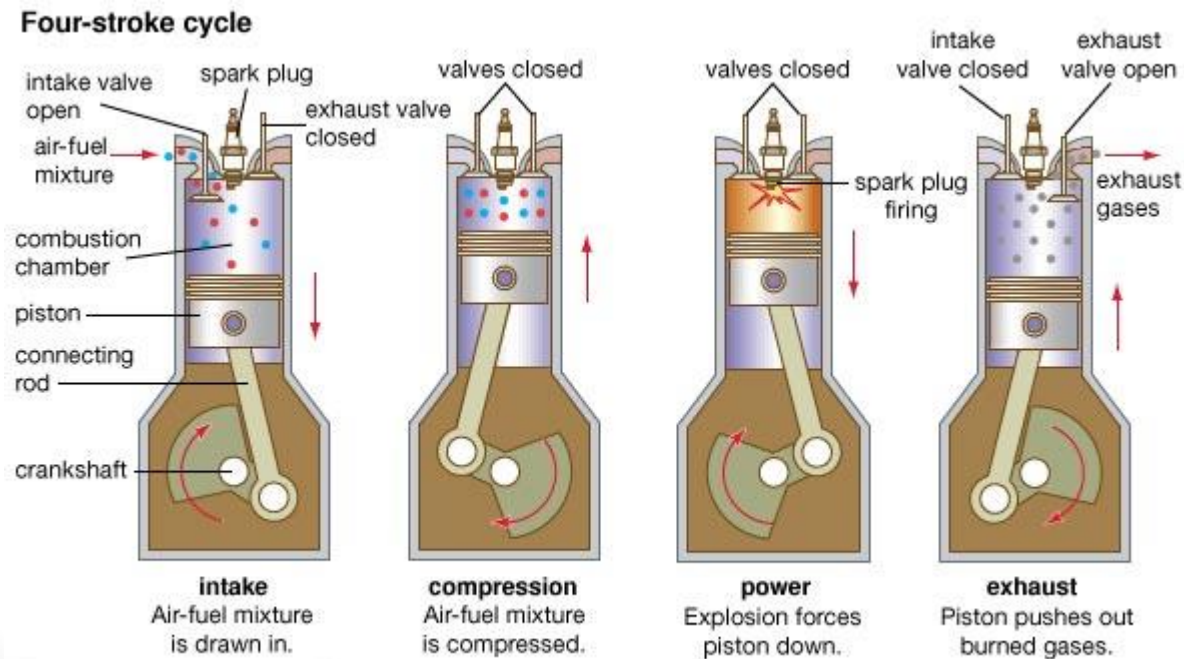


## The Laws of Thermodynamics

The car engine is **heat engine** because it first transforms the chemical energy of the gasoline molecules into heat by burning the gasoline with oxygen from the air (Heat of reaction).

The released heat is transformed into Pressure-Volume work by causing the hot combustion gases to expand inside of a cylinder in the engine.

This work energy is transferred to the piston and crankshaft, and then to the wheels of the car.



## The Laws of Thermodynamics

As another example, one can think of a coal-burning train going from one city to another.



## The Laws of Thermodynamics

Think of a coal-burning train going from one city to another:

At the beginning, the coal represents low-entropy matter and energy, usable energy available for producing work.

During the trip, useful work is performed, but at the same time the coal is being transformed into ashes and combustion gases, high-entropy unusable materials.

Again we can see the laws of thermodynamics in action. The quantities of matter and energy present originally have been conserved, but there has occurred an irrevocable qualitative change: entropy has increased.

## Entropy and Information

Claude Shannon, 1948:

“Information is the negative of entropy.”

$$\Delta I = -\Delta S$$

This means that, for a system, an increase in information is equal to a reduction in entropy.

For example, the information contained in its strands of DNA can be used by a living cell to make a copy of itself; the entropy of the materials to make the new cell has been reduced.

Another example: A compact-disk (CD) containing the plans to make a house can be used by a carpenter to build the house; the entropy of the materials to make the new house has been reduced.

## Entropy and Economics

Low-entropy, organized structures have economic value, for example, a building, an iron nail, or a live horse.

Money is a means of exchange of economic value, that is, it represents information about negative entropy.

So, money is information about negative entropy. It indicates a particular amount of negative entropy and also the specific entity that is accrued that amount of negative entropy.

## Entropy and Economics

Economics studies the flows of money and of goods and services in a society.

The relation between economics and thermodynamics is that money is payment for goods received or for services rendered.

Economically valuable goods:

Are material objects that have had their entropy reduced.

Economically valuable services:

Are processes that reduce entropy.

In an economic transaction, money represents trustworthy information about a specific amount of negative entropy, to the buyer, and also to the seller.

## Entropy and Economics

What is MONEY?

Money is INFORMATION about economic value.

The clearest PROOF that money is simply information can be seen in the fact that present-day money is simply a series of ones and zeroes in the computer memory of some financial institution. The information that stored in this computer memory is the AMOUNT of money and the OWNER of this particular amount of money.

In medieval times, instead of in a computer memory, the same kind of information would have been written down in a paper ledger: A certain amount of money and who was the owner of this particular amount of money.

And in antiquity, it would have been the actual physical reality that encoded the information. If Gilgamesh was given 10 ounces of gold in payment, the amount of money was 10 ounces of gold, and the owner was Gilgamesh.

# Conclusions: The Laws of Thermodynamics

- The First Law of Thermodynamics
  - Energy must have a source: You cannot create energy out of nothing.
  - You purchase gasoline at a gas station: The gasoline contains usable energy.
  - You purchase food at the grocery store: The food contains usable energy.
- The Second Law of Thermodynamics
  - Each particular amount of usable energy can be used only ONE time.
  - That is why you pay money to purchase gas or food.
- The reason for the value of money is that usable energy cannot be recycled.



The **entropy,  $S$** , is “a measure of the disorder or disorganization of a system.” ☺

## References

- Chen, Jing and Galbraith, James K., 2009. *A Biophysical Approach to Production Theory*. <[http://utip.gov.utexas.edu/papers/utip\\_55.pdf](http://utip.gov.utexas.edu/papers/utip_55.pdf)>. Accessed 17 February 2012.
- Malley, Konstantin, Singh, Ravneet and Duan, Tianyu, 2016. *The Second Law of Thermodynamics*. LibreTexts. <[https://chem.libretexts.org/Textbook\\_Maps/Physical\\_and\\_Theoretical\\_Chemistry\\_Textbook\\_Maps/Supplemental\\_Modules\\_\(Physical\\_and\\_Theoretical\\_Chemistry\)/Thermodynamics/The\\_Four\\_Laws\\_of\\_Thermodynamics/Second\\_Law\\_of\\_Thermodynamics](https://chem.libretexts.org/Textbook_Maps/Physical_and_Theoretical_Chemistry_Textbook_Maps/Supplemental_Modules_(Physical_and_Theoretical_Chemistry)/Thermodynamics/The_Four_Laws_of_Thermodynamics/Second_Law_of_Thermodynamics)> Accessed 23 October 2018.
- Planck, Max, 1903. *Treatise on Thermodynamics*. Longman and Greens. <[http://openlibrary.org/books/OL7080724M/Treatise\\_on\\_thermodynamics](http://openlibrary.org/books/OL7080724M/Treatise_on_thermodynamics)>. Accessed 23 May 2013.
- Shannon, Claude E., 1948. *A Mathematical Theory of Communication*. Bell System Technical Journal, vol. 27, p. 379-423 and 623-656, July and October. <<https://archive.org/details/ShannonClaudeEWeaverWarrenTheMathematicalTheoryOfCommunication1963>>
- Wikipedia, 2012. *Thermoeconomics*. <<http://en.wikipedia.org/wiki/Thermoeconomics>>. Accessed 17 February 2012.