Key terms

The **first law of thermodynamics** is the **principle of conservation of energy**, which states that energy in an isolated system can be transformed but cannot be created or destroyed.

Energy in systems

Energy in all systems is subject to the laws of thermodynamics.

According to the **first law of thermodynamics**, energy is neither created nor destroyed. What this really means is that the total energy in any isolated system, such as the entire universe, is constant. All that can happen is that the form the energy takes changes. This first law is often called the **principle of conservation of energy.**

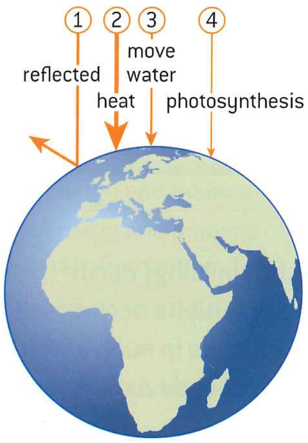


Figure 1.3.2 The fate of the Sun's energy hitting the Earth. About 30% is reflected back into space (1), around 50% is converted to heat (2), and most of the rest powers the hydrological cycle: rain, evaporation, wind, etc (3). Less than 1% of incoming light is used for photosynthesis (4).

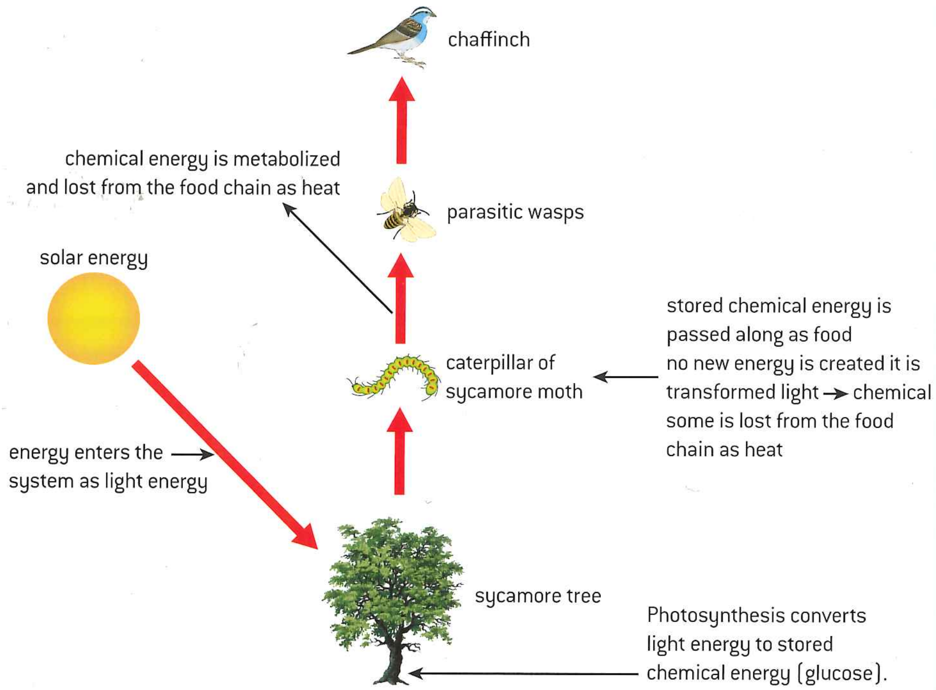


Figure 1.3.1 A simple food chain

In a power station, one form of energy (from eg coal, oil, nuclear power, moving water) is converted or transformed into electricity.

In your body, food provides chemical energy which you convert into heat or kinetic energy.

If we look at the sunlight falling on Earth, not all of it is used for photosynthesis.

The **second law of thermodynamics** states that the **entropy** of an isolated system not in equilibrium will tend to increase over time.

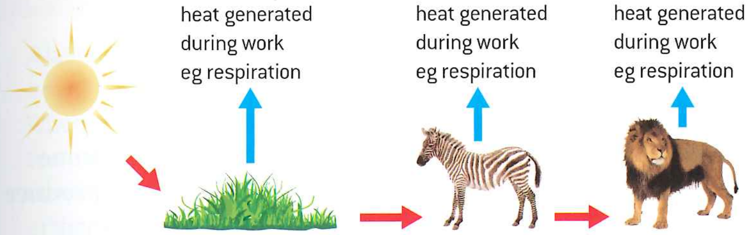
- Entropy is a measure of disorder of a system and it refers to the spreading out or dispersal of energy.
- More entropy = less order.
- Over time, all differences in energy in the universe will be evened out until nothing can change.
- Energy conversions are never 100% efficient.
- When energy is used to do work, some energy is always dissipated (lost to the environment) as waste heat.

This process can be summarized by a simple diagram showing the energy input and outputs.

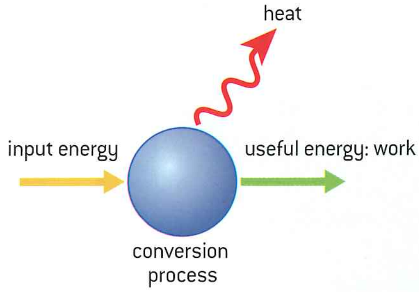
Key terms

The **second law of thermodynamics** refers to the fact that energy is transformed through energy transfers. **Entropy** is a measure of the amount of disorder in a system. An increase in entropy arising from energy **transformations** reduces the energy available to do work.

energy = work + heat (and other wasted energy)



▲ **Figure 1.3.4** Loss of energy to the environment in a food chain



▲ **Figure 1.3.3** The second law of thermodynamics

In the example in figure 1.3.4, the energy spreads out so the useful energy consumed by one trophic level is less than the total energy at the level below.

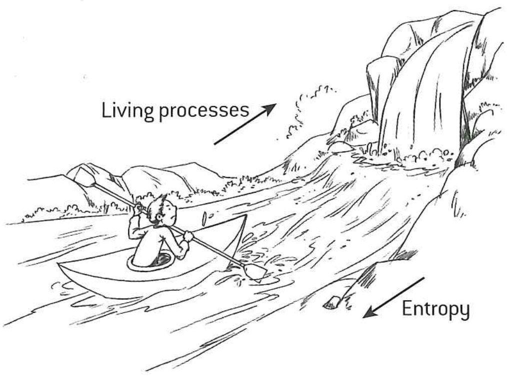
- Depending on the type of plant, the efficiency at converting solar energy to stored sugars is around 1–2%.
- Herbivores on average only assimilate (turn into animal matter) about 10% of the total plant energy they consume. The rest is lost in metabolic processes and escaping from the carnivore. This changes the stored chemical energy in its cells into useful work (running). But during its attempted escape some of the stored energy is converted to heat and lost from the food chain.
- A carnivore's efficiency is also only around 10% (see 2.3). As with the herbivore they metabolize stored chemical energy, in this case trying to catch the herbivore.
- So as energy is dispersed to the environment, there will always be a reduction in the amount of energy passed on to the next trophic level.
- That means the carnivore's total efficiency in the chain is $0.02 \times 0.1 \times 0.1 = 0.0002\%$.
- This means the carnivore loses most of its energy as heat into the surrounding environment.

Key term

Entropy is a measure of the amount of disorder in a system.

Life is a battle against entropy and, without the constant replenishment of energy, life cannot exist. Consider this pictorial view (figure 1.3.5) of paddling upstream. Stop for a moment and you are swept back downstream by the current of entropy.

Simple example of entropy:



▲ **Figure 1.3.5** A representation of life against entropy

Tidy room has order: low entropy
Does this happen naturally without the input of energy?

Untidy room has disorder: high entropy

▲ **Figure 1.3.6** Which is your room?

The situation depicted in figure 1.3.6 obeys the second law of thermodynamics, since the tidy room of low entropy becomes untidy, a situation of high entropy. In the process, entropy increases spontaneously.

Solar energy powers photosynthesis. Chemical energy, through respiration, powers all activities of life. Electrical energy runs all home appliances. The potential energy of a waterfall turns a turbine to produce electricity. These are all high-quality forms of energy, because they power useful processes. They are all ordered forms of energy. Solar energy reaches us via photons in solar rays; chemical energy is stored in the bonds of macromolecules like sugars; the potential energy of falling water is due to the specific position of water, namely that it is high and falls. These ordered forms have low disorder, so low entropy.

On the contrary, heat may not power any process; it is a low-quality form of energy. Heat is simply dispersed in space, being capable only of warming it up. Heat dissipates to the environment without any order; it is disordered. In other words, heat is a form of energy characterized by high entropy.

To think about

Implications of the second law for environmental systems

We experience the second law in our everyday lives. All living creatures die and in doing so:

- entropy or disorder tends to increase
- the creatures move from order to disorder
- but organisms manage to 'survive' against the odds, that is against the second law of thermodynamics
- living creatures manage to maintain their order and defy entropy to stay alive by continuous input of energy by continuously getting chemical energy from organic compounds via respiration
- energy is even required at rest – if they do not respire they die.

This is the same as the example of the room; the only way to keep the room tidy is to continuously clean it, that is to expend energy.

In any process, some of the useful energy turns into heat:

- Low-entropy (high-quality) energy degrades into high-entropy (low-quality) heat.
- So the entropy of the living system stays low, whilst the entropy of the environment is increasing.
- Photosynthesis and respiration are good examples.
  - Low-entropy solar energy turns into higher-entropy chemical energy.
  - Chemical energy turns into even higher-entropy mechanical energy and is 'lost' as heat (low-quality, high-entropy).
- This increases the entropy of the environment, in which heat dissipates.
- As a consequence, no process can be 100% efficient.

TOK

A last philosophical implication is that, according to physics, the fate of all the energy that exists today in the universe is to degrade into high-entropy heat. When all energy has turned into heat, the whole universe will have a balanced temperature, and no process will be possible any longer, since heat may not turn into something of higher entropy. This is referred to as the thermal death of the universe.

What may happen after that?

Key term

Efficiency is defined as the useful energy, the work or output produced by a process divided by the amount of energy consumed being the input to the process:

efficiency = work or energy produced / energy consumed

efficiency = useful output/ input

Multiply by 100%, if you want to express efficiency as a percentage.

Complexity and stability

Most ecosystems are very complex. There are many feedback links, flows and storages. It is likely that a high level of complexity makes for a more stable system which can withstand stress and change better than a simple one can, as another pathway can take over if one is removed. Imagine a road system where one road is blocked by a broken-down truck; vehicles can find an alternative route on other roads. If a community has a number of predators and one is wiped out by disease, the others will increase as there is more prey for them to eat and prey numbers will not increase. If on the other hand systems are simple they may lack stability.

- Tundra ecosystems are fairly simple and thus populations in them may fluctuate widely, eg lemming population numbers.
- Monocultures (farming systems in which there is only one major crop) are also simple and thus vulnerable to the sudden spread of a pest or disease through a large area with devastating effect. The spread of potato blight through Ireland in 1845–8 provides an example; potato was the major crop grown over large areas of the island, and the biological, economic and political consequences were severe.

Key term

Negative feedback loops are stabilizing and occur when the output of a process inhibits or reverses the operation of the same process in such a way to reduce change – it counteracts deviation.

Equilibrium

Equilibrium is the tendency of the system to return to an original state following disturbance; at equilibrium, a state of balance exists among the components of that system.

We can think of systems as being in dynamic (steady-state) or static equilibria as well as in stable or unstable equilibria. We discuss each of these here. Note that the term steady-state equilibrium is used instead of dynamic equilibrium in this book.

Open systems tend to exist in a state of balance or stable equilibrium. Equilibrium avoids sudden changes in a system, though this does not mean that all systems are non-changing. If change exists it tends to exist between limits.

A **steady-state equilibrium** is a characteristic of open systems where there are continuous inputs and outputs of energy and matter, but the system as a whole remains in a more-or-less constant state (eg a climax ecosystem).

Key term

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