Science and Technology

PART ONE: HOW SCIENCE & TECHNOLOGY IMPACTS THE ENVIRONMENT

Be sure to view the slides in “Slide Show” mode

Definitions:

SCIENCE: "Devoted to the conceptual enterprise of understanding and describing the physical and biological world."

TECHNOLOGY: "Fabrication and use (of) devices and systems," or "Science plus purpose," or "organization of knowledge for the achievement of practical purposes."

The scientific method

- Identify a problem to be solved
- Construct a hypothesis
- Test the hypothesis through experiment
- If the hypothesis fails, re-evaluate
- If the hypothesis holds after repeated experiments, it becomes a theory (i.e., a model), which should be *descriptive*, *testable* and *predictive*.

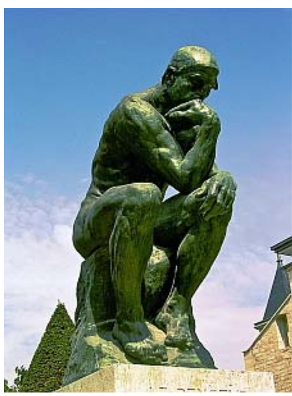
3.2. The Rôle of Science & Technology

Science

- Provides a theoretical foundation for the development of technology.
- Scientific “intellectual capital” usually grows over time, rarely falls.
- Provides a means for analyzing and understanding environmental problems- allowing solutions to be found.
- Unfortunately the majority of the world’s people don’t understand much science- including many intellectuals! (*Two Cultures*).

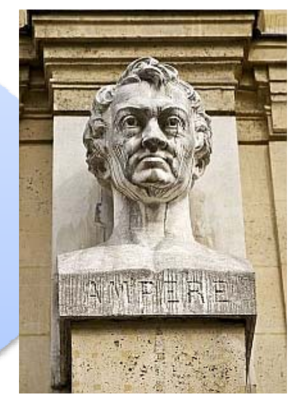
The Two Cultures – C.P. Snow

Many members of the public are weak in science. They have a respect for science & technology, but also a great fear of its effects- particularly rapid change.



Many non-scientist intellectuals fail to understand science, and they foster an atmosphere of fear & suspicion.

Many scientists respond in a way that comes across as arrogant and condescending.



Technology

- Technology has freed humans from mere survival, allowed pursuit of other activities from industry to poetry.
- Results in more comfortable lifestyle, less uncertainty in survival, and higher life expectancy. Can sustain higher populations.
- However more is not always better! Should not be an end in itself!
- Not inherently polluting! However the growth in population & per capita consumption does lead to pollution.

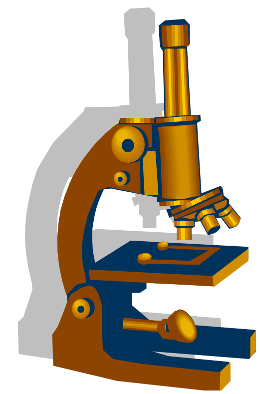
Joseph Schumpeter (1883-1950)

- Czech economist
- Argued that technical progress is the engine of economic growth.
  [No innovation=> no growth]
- Supported “imperfect” markets with oligopolies.
- Cycle of innovation: Oligopolies will keep innovating in order to keep their privileged position (e.g. Microsoft!)

How science & technology can cause harm

- Science may lead to discoveries (nuclear energy) which are then used for negative purposes (e.g., nuclear weapons).
- Technology is developed with a purpose in mind. If the purpose is genocide, then it is clearly harmful.
- Unexpected “side effects” and “revenge effects.”

Example: Modern Medicine



EFFECT OF MODERN MEDICINE ON THE ENVIRONMENT:

- Higher life expectancy.
- This means that the Earth's population can grow rapidly without incidents like the "Black Death."
- Far higher population has a much greater impact on the environment.
- Should we ban modern medicine?

We should conclude:

- Science & technology are *tools*. They are not inherently pro- or anti- environment. Only the purposes to which we apply them are.
- Despite this, we need to watch out for unexpected side/revenge effects.

Why not harness science & technology *for* the environment?

- If science is asked to study environmental problems, we can find ways to protect natural capital (see the pike example above).
- Meanwhile we can develop technology with the specific purpose of reducing our environmental impact.

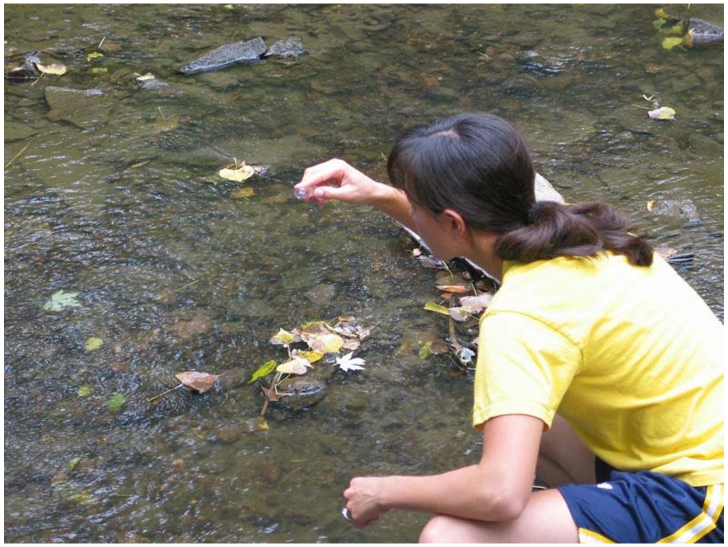
Environmental technology

- New tools for scientists to study the environment (e.g. to detect Al^{3+} levels in water).
- New “green” products, such as biodegradable plastic, fuel cell cars.
- New “green” processes for making things- cleaner chemical processes, energy efficient manufacturing methods, etc.
- New “green” engineering methods- design machinery to be inherently benign/efficient.

3.3. Environmental Sciences

Environmental Science

- Studies the environment, including aspects relating to:
  - Chemistry (e.g. environmental chemistry)
  - Physics
  - Biology (e.g., ecology)
  - Geology
  - Meteorology
- Topics studied include
  - Global warming
  - Acid rain
  - Pollution
  - Biodiversity and conservation
  - Waste management



Iowa state student sampling water from a stream. Picture by Alloquep from Wikipedia, CC licence.

Sustainability science

The US National Academy of Sciences gives three main tasks for sustainability science:

1. Develop a research framework that integrates global and local perspectives to shape a "place-based" understanding of the interactions between environment and society.
2. Initiate focused research programs on a small set of understudied questions that are central to a deeper understanding of interactions between society and the environment.
3. Promote better utilization of existing tools and processes for linking knowledge to action in pursuit of a transition to sustainability.

Sustainability science

- Multidisciplinary approach to solving sustainability problems scientifically. Combines the "hard" sciences such as chemistry with social sciences such as economics and sociology.
- Focuses on the nature-society interface, rather than on the study of nature in isolation.

Environmental chemistry

- Defined as: “The chemistry of surroundings” (vanLoon & Duffy, *Environmental Chemistry*, Oxford, 2000.).
- Environmental chemists study the chemical composition of the environment, and look for the presence of pollutants. They then develop hypotheses and theories to explain the impact of certain materials on the environment.
- Not to be confused with “green chemistry”, which is concerned with pollution prevention.

Environmental chemistry

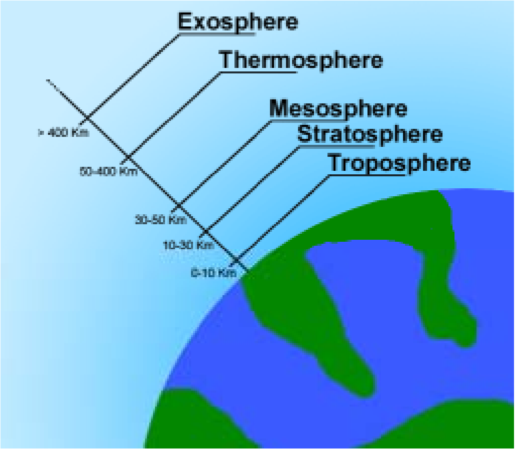
- Environmental chemistry has provided us with an understanding of many key environmental issues:
  - Acid rain
  - The “greenhouse effect”
  - Depletion of the ozone layer by CFCs
  - Dioxins
- Traditionally built upon analytical chemistry, to analyze chemicals in the environment.

Environmental chemists frequently use GC-MS to analyze samples. The technique can detect very low concentrations of pollutants.
Picture: NINT

Environmental chemistry

The topic is usually broken down into three main areas of focus:

1. The atmosphere
   - Includes the greenhouse effect, and all forms of air pollution (ozone, acid rain, etc.)
2. The hydrosphere
   - Studies topics such as water pollution, water purification, pH, etc.
3. The terrestrial environment
   - Includes soil science, rocks, mining, etc.



Picture by Bredk.
From WM Commons

Ecology

- Defined as: “The study of the interrelationships among plants and animals and the interactions between living organisms and their physical environment.”*
- Studies topics such as biodiversity and population dynamics.
- An ecosystem is the unit of ecology, containing the biological and physical components in relation to one another.

*Turk, Wittes, Turk & Wittes, Environmental Science, 2nd. Ed., Saunders, 1978.

The kelp forest exhibit at the Monterey Bay Aquarium. Picture by Stef Maruch , CC licence, from WM Commons

Conclusion

- Science provides us with:
  - Environmental data
  - Theories based on these data that aid our understanding, and which can predict effects such as global warming.
- Thus, science provides a rational framework for nearly all environmental debate.
- Once we understand the science, technology may provide a solution to the environmental problem. Technological solutions will be covered in depth later in the course.

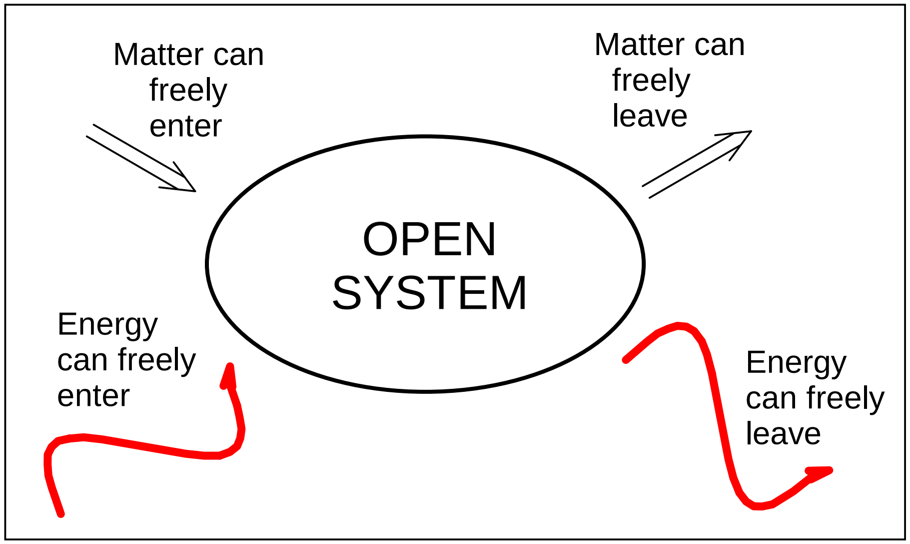
Unit 3
Science & Technology

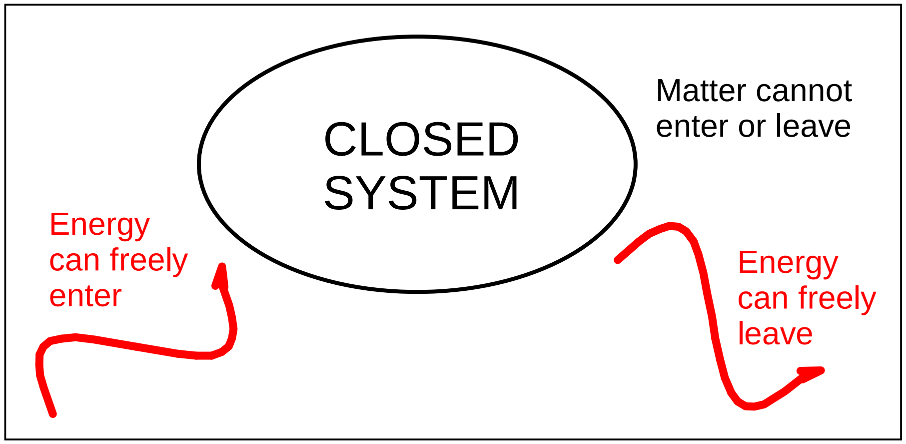
PART TWO:

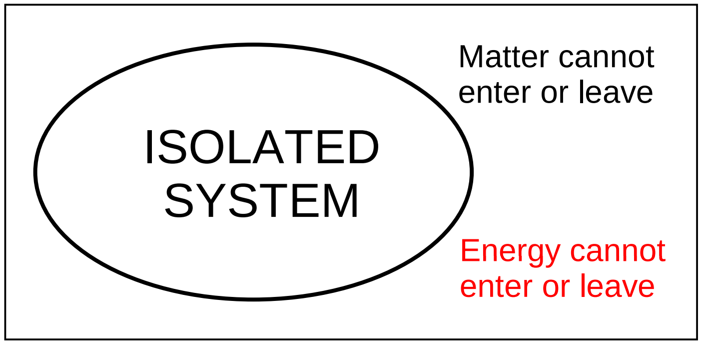
MATTER, ENERGY & THERMODYNAMICS

First, a definition

A **thermodynamic system** is a collection of matter & energy with a physical boundary. There are three types:







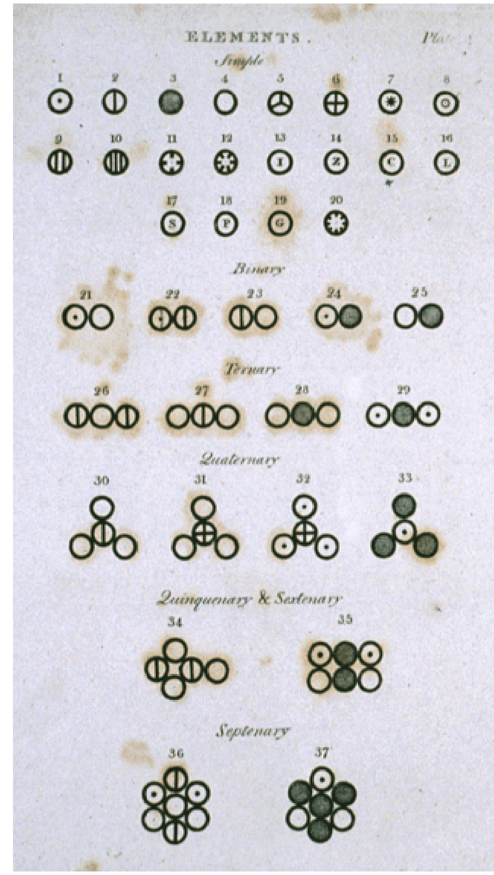
MATTER

What is matter made of?

- According to Dalton's Atomic Theory, matter is composed of **atoms** – small indivisible particles.*
- All atoms of a given **element** are alike - thus a carbon atom is always the same.

We now know these statements are simplifications, but for ordinary chemical processes this simple theory approximates to the truth.

- There are only about 90 different elements commonly found on Earth.
- Dalton's theory was built upon several basic chemical laws.



From Dalton, *A New System of Chemical Philosophy*, 1808

Law of Constant Composition

- A pure substance will always have the same composition.
- This means that the proportions of the elements in the substance will always be identical. In this form, it is often referred to as the **Law of Definite Proportions.**

For example methane (CH_4, natural gas) always contains 25% hydrogen by mass, and 75% carbon by mass.

Law of Conservation of Mass

- In any chemical or physical process, the total mass involved will always remain the same.
- When we observe mass to be lost, this is from mass lost out of the system (e.g., carbon dioxide and steam lost when wood is burned)

Again, this is a slight simplification that is still true for ordinary processes. Strictly speaking it is matter-energy that is conserved.

Priestley's reversible formation of mercury(II) oxide from mercury & oxygen helped in formulating this law. Picture by MaterialScientist CC-BY-SA-3.0

ENERGY & THERMODYNAMICS

Classical thermodynamics and the thermodynamic laws

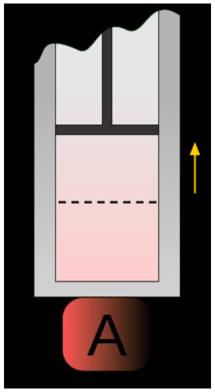
- In the 19th century, scientists made the connection between heat and mechanical work. This connection is epitomized by the steam engine and the railroad.
- There are three classical laws of thermodynamics (1st, 2nd, 3rd), and a fourth came later and is known as the "Zeroth law". See the next slides for details.

Joule used this apparatus to make the fundamental connection between heat and work. [Picture](#) from Wikimedia C

First Law of Thermodynamics

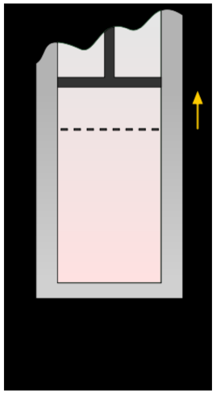
Change in internal energy in a closed system

= heat energy supplied + work done



Can also be formulated as

Energy can be neither created nor destroyed

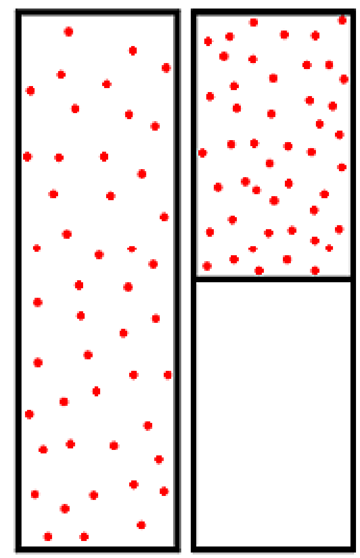


In everyday life we perceive energy being "lost" (heat lost through an open window, etc.), but in practice the energy is simply dissipated into the wider environment.

Second Law of Thermodynamics

This can be formulated in several ways:

- *Processes that are spontaneous in one direction are not spontaneous in the other direction*
- *Heat cannot pass from one body to a hotter body* (as immortalized in **this song**!)
- *The entropy for an isolated system not at equilibrium will increase with time until it reaches equilibrium.*

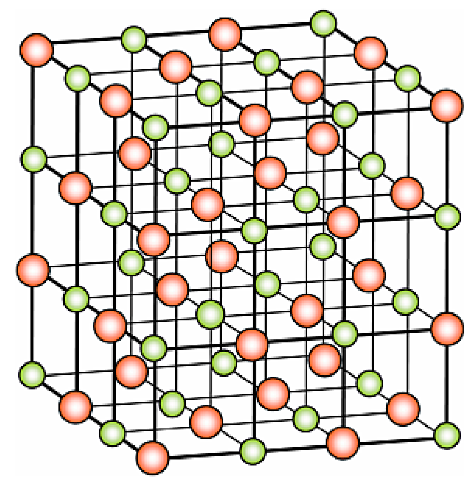


A result is seen in the Carnot cycle – a heat engine can never be 100% efficient

Third Law of Thermodynamics

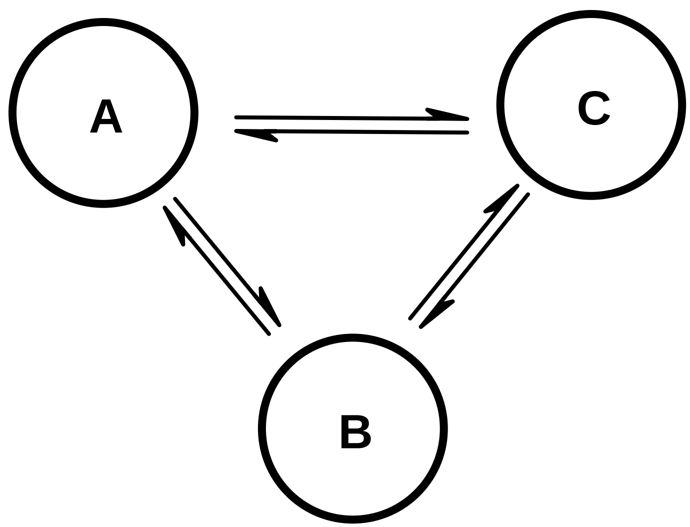
The entropy of a perfect crystal approaches zero as the temperature of the crystal approaches absolute zero temperature.

- A result of this is that it is impossible for matter to reach absolute zero by purely thermodynamic processes, though it may come extremely close.
- Absolute zero is zero K, -273.26 ^{o}C, -459.67 °F.



Zeroth Law of Thermodynamics

If two systems are separately in thermodynamic equilibrium with a third system, then they are also in equilibrium with each other.



In this context, equilibrium means a state of balance – the heat flowing from A to B is equal to that flowing from B to A.

Spontaneous processes

- In both physical and chemical processes it is often seen that A converts to B spontaneously. In such cases, B will never spontaneously convert back to A.
- Examples:
  - Salt dissolving in water
  - Iron rusting in air (see p32 of Hill, which has major errors in the rusting equation!)
  - TNT exploding
  - Carbon dioxide from your car engine dispersing into the air

Picture by Chris 73, From Wikimedia Commons, CC license

Gibbs Free Energy

The spontaneity of a process is determined by two factors:

- The heat change that occurs (ΔH)
- The entropy change (ΔS) that occurs, multiplied by the temperature in Kelvins. (T)

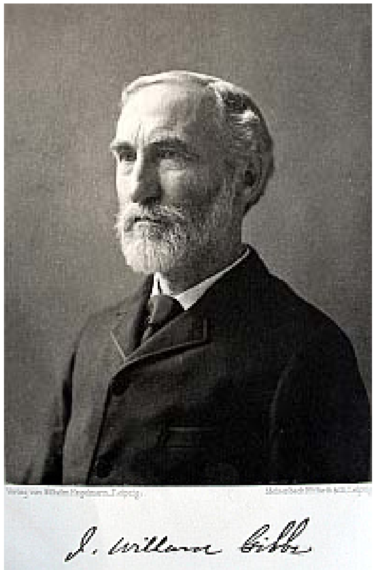
(The Δ or delta symbol means "change of")

This is summarized in the equation:

$$\Delta G = \Delta H - T\Delta S$$

where ΔG is called the "Gibbs Free Energy"

- If ΔG is negative, the process is spontaneous. If DG is positive, the process is not spontaneous. If DG is zero, the system is at equilibrium.
- As the temperature increases, the effect of entropy becomes more prominent.



JW Gibbs

$\Delta G = \Delta H - T\Delta S$

- If ΔG is negative, the process is spontaneous.
- If DG is positive, the process is not spontaneous.
- If DG is zero, the system is at equilibrium.
- As the temperature increases, the effect of entropy becomes more prominent. Some examples:
  - It takes a heat change (ΔH) to boil water, but when the temperature gets hot enough, the water boils spontaneously because now $T\Delta S$ exceeds ΔH.
  - Heat is needed to force hydrocarbons to be “cracked” at high temperature in a petrochemical plant. The process occurs because the products (such as ethylene) - though less stable – have a higher entropy than the starting materials

Will a spontaneous process always occur?

- The Gibbs Free Energy tells us whether or not a process goes downhill in energy. However, it tells us nothing about the possibility of an ***energy barrier*** that prevents the process from happening – in either direction!
- The energy barrier for a chemical process is determined by ***kinetics*** – the study of reaction rates.
- Why don't wood or petroleum catch fire and burn spontaneously in air? They do not ordinarily have enough energy to cross the energy barrier.

Lake Issyk Kul lies above 5000 ft, yet the water does not flow out spontaneously - it is surrounded by high mountains.

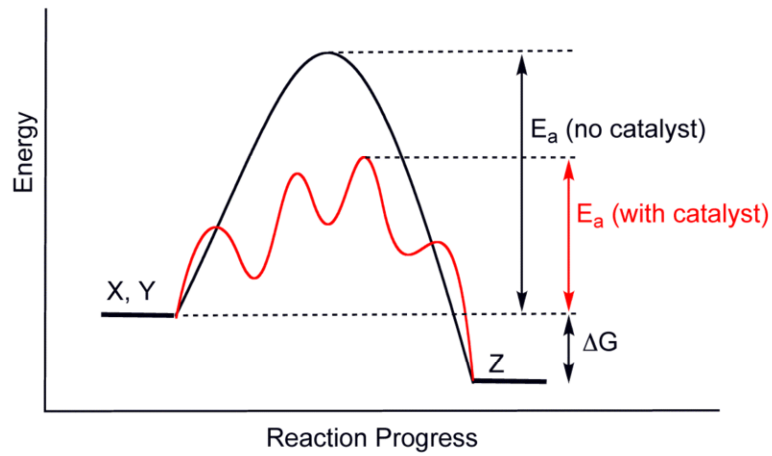
Life on Earth

- The burning of plants in air is a spontaneous, yet the Earth is covered with plants. This is possible because of the energy barrier for combustion. This allows the plants to exist far from equilibrium (which favors carbon dioxide + water)
- We can summarize life as follows:

$$CO_2 + H_2O \underset{\text{Animals}}{\overset{\text{Plants (photosynthesis)}}{\rightleftarrows}} \text{Carbohydrates} + O_2$$

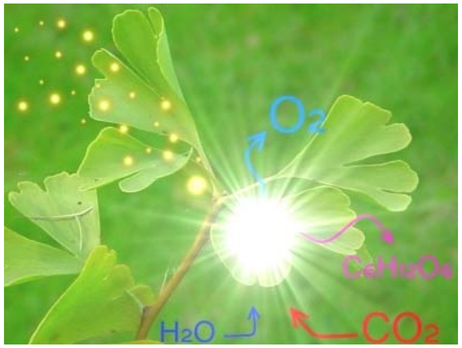
Catalysts and enzymes

- How can we help a spontaneous chemical process overcome an energy barrier? By using a **catalyst**.
  - A catalyst does not change ΔH, it simply lowers the energy barrier by providing an alternative pathway
  - This is equivalent to drilling a hole through the mountains to drain Lake Issyk Kul
  - A biochemical catalyst is called an **enzyme**.
- Examples of catalysts:
  - A catalytic converter in a car
  - Yeast for brewing



Here, E_a represents the energy barrier

Exergy



- Exergy is the maximum of useful work that can be done by bringing a system to equilibrium. It can be regarded as the "embodied energy" of a system – its capacity to do work.
- It is often the same as the Gibbs Free Energy.
- We can consider that plants use energy from the Sun to produce plant matter (carbohydrates, etc.) that contain exergy; when we eat or burn these plants we extract some of this exergy.
- Exergy gives a useful way to compare energy sources in sustainability measurements.