Big Sustainability

Mark Ciotola

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Contents

1

Introduction to Big Sustainability

Learning Objectives: describe what is Big Sustainability and why it is important.

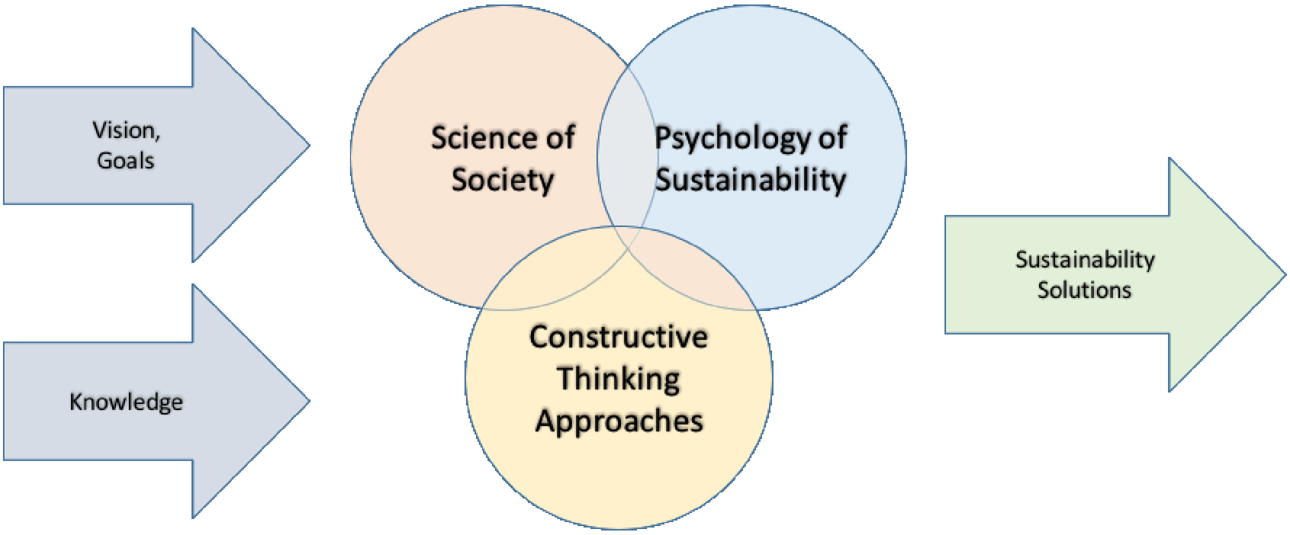
What Is Big Sustainability?

Big Sustainability encompasses macroscopic, integrated approaches to sustainability, including environmental, economic and social sustainability. Big Sustainability involves large-scale, integrated systematic thinking. It recognizes that multi-century "soft" physical forces exist that act to push society along certain paths.

Big Sustainability involves several branches.

- *Unified science*, including a science of society.
- Constructive *thinking approaches*
- The *psychology of sustainability and human decision-making*, especially when such occurs in very large groups.

Big Sustainability strives to bring the goals of humanity through the filters of physical, social and psychological reality to develop a framework for identifying robust, practicable solutions to sustainability challenges.



Three areas of Big Sustainability

Why Is Big Sustainability Important?

Environmental sustainability cannot happen without economic and social sustainability. If humans feel stressed, environmental sustainability will be a low priority. Consequently, excessive use of renewable resources and rampant destruction of the environment will be more likely to occur. Consequences of that stress include environmental damage caused by wars and accelerated use of nonrenewable resources.

In the past, disruptive events as such war might last a few years, and then ecosystems would recover during times of peace. Destruction in one part of the world could be offset since other parts would remain intact and help with the recovery. Yet, in current times, a global nuclear war can destroy the Earth's entire ecosystem. Or, given the international interdependency of national economies, severe economic shocks can lead to global economic collapse, and nearly did so in 2008. Even conventional wars, such as Syria's civil war in , has lead to a refugee problem that encouraged in the partial break-up of Europe (e.g the Brexit) and the fall of several democracies. In reaction to globalism, there are nationalist and fascist movements in many developed countries that threaten the freedom of speech to vital to gain and spread the knowledge required to overcome human crises.

Thousands of dedicated activists and scientists work on sustainability. Yet despite there have been some successes, humanity and the environment are rushing towards a catastrophic future. Just climate change itself may lead to the end of complex life on Earth. There may be several reasons for this lack of success. First, we do not sufficiently understand the psychology of sustainability and human decision-making, especially when they occur in very large groups. Second, we do not sufficiently recognize and understand medium-term "soft" physical forces that push society along certain paths. Finally, there is a lack of really large-scale, integrated systematic thinking.

Big Sustainability strives to better understand and overcome these challenges. These challenges are embodied by the following parable.

The Scientists and The Elephant

There is an old parable that illustrates the importance of systematic thinking which is fundamental to Big Sustainability.

> It was six scientists
> To learning much inclined,
> Who went to see the Elephant
> (Though the night was dark as coal),
> That each by observation
> Might satisfy their minds
>
> They conclude that the elephant is like a wall, snake, spear, tree, fan or rope, depending upon where they touch.
>
> And so these scientists
> Disputed loud and long,
> Each in their own opinion
> Exceeding stiff and strong,
> Though each was partly in the right
> And all were in the wrong.

This parable is a modern adaptation of the *Blind Men and the Elephant,* by American poet John Godfrey Saxe (1816-1887) which in turn was based upon a fable told in India many years ago.

2

Understanding Ourselves

Learning objectives: understand biases of ourselves and others that can affect the interpretation of information and negatively impact decision-making, and to learn strategies for overcoming those biases.

Thinking Reactions

How we feel about a topic, news or information may color our assessment of its validity or relevance. Therefore it is important to understand how we feel about a topics and statements before we consider their validity. It is also important to understand the sources of our biases, the consequences of those biases and strategies to overcome them.

- There are several thinking reactions that can affect and distort our thinking. Awareness of these reactions, their consequences and strategies to overcome them can help strengthen one's thinking.
- Even if we know about these reactions already, they are easy to forget. Hence it is good to frequently review them.

Dueling Parts of the Human Brain

At the core of the human brain is a *reptile* brain. This brain is reactive and reflexive. It is useful for quick reactions such as immediate danger and fighting. Many of our base emotions are within this layer.

On top of the reptile brain is a *mammal* brain. The mammal brain is much more socially aware. Our emotions such as love come from this layer. Our ability to interact in groups comes from this layer as well.

✘ Reaction

Your initial reactions will tend to be negative and uninformed.

→ Consequence

You will react to ideas with your reptile brain and make poor decisions.

✓ Strategy

Wait until you are calm to make key decisions or interpret important facts.

Action-Rationality Paradox

The *action-rationality paradox* is related to the duel existence of reptile and mammal brains. To motivate ourselves, we need to activate our reptile brain. We need to boost our confidence and tell ourselves, we can "do anything", "beat any odds." It can help increase our adrenaline levels and increase the chances of success during battle. Unfortunately, much of the reptilian "hype" is nonsense. To think rationally, we need to use our mammalian brain, such as to plan a battle.

Here is the paradox: if we use our reptile brain to plan a battle, it will decrease our chances of victory. If we use our mammalian brain to fight a battle we will react more slowly and less strongly. So we cannot use the same part of our brain to plan and fight.

✓ Strategy

Think rationally about goals and plans, then tell oneself a lot of nonsense when one goes into battle (or give a presentation or interview for a job).

Confirmation Bias

✘ Reaction

We tend to believe things that confirm what we already believe.

→ Consequence

We become more and more convinced of something regardless of what most external evidence is telling us.

✓ Strategies

- Identify what you want to believe before interpreting facts.
- Be especially critical of and triple-check any facts that confirm your existing biases or make you feel good.

Kill-the-Messenger Syndrome

✘ Reaction

We tend to reward or punish the deliverer of a message based upon the favorability of the content, due to the immediate reaction of our reptile brain. This is known as *kill the messenger* syndrome.

→ Consequence

This syndrome has the effect that people are hesitant to deliver bad news, so we may not receive important information.

✓ Strategies

- **For the message recipient:** remind oneself to save one's reaction to the message for the party responsible for is contents.
- **For the message deliverer:** try to take measures to mitigate the impact of any negative content. Be ready with solutions.

Concepts of Perception of Time

✘ Reaction

We humans tend to think of time in terms of:

- Now
- Soon
- Infinity

➔ Consequence

This makes it difficult for people to think about and plan for the "medium term" (i.e. the time between soon and infinity). Sustainability efforts are often targeted at infinity or 10,000+ years. Yet, we live our lives in real time. The Earth's eco-system may be saved or destroyed within the next 50 years (or less), not now or in 1000 years.

- Bad stuff may happen before we get to infinity.
- In real systems, infinity = equilibrium = death

✓ Strategy

Write out timelines and schedule milestones. Don't just keep it in your head, because the human brain does not have enough "time bins". Also, remind oneself that solutions designed for excessively-long periods of time often tend to be inflexible.

Coldness of Math

✘ Reaction

Most people distrust math and quantitative reasoning.

➔ Consequence

Many people may get hurt to save the few. Many impractical options are acted upon.

✓ Strategy

Do the math. Calculate the odds as best as possible. Multiply them by the value of the impact of each potential outcome. Every number should either be a ratio or expressed in units.

Bias Towards the Local

✗Reaction

We often favor what we know and can control. We have the most information and influence over local phenomena, from which we can get the most immediate, certain benefits. This also tends to be our comfort zone. We have a distrust over big things, especially those we know little about. So we often miss the big picture.

→ Consequence

We overlook system effects and interdependencies. We neglect the big picture, which may be far more significant.

✓ Strategy

Take the effort to see the big picture, and the impact of the local and global pictures on each other.

Fatalism

✗Reaction

There is often the belief that we cannot change anything, or at least not the big things. Although this can sound disempowering, it has the benefit that we absolve ourself of any responsibility for positive change.

→ Consequence

Likewise, this can also result in a false idealism. There is the feeling that since we cannot make change, we should adopt the most idealistic position possible regardless of its practicality.

✓ Strategy

Remember that effort typically pays off, even if not in ways expected.

Quiz

3
Hard, Visible Challenges Versus Soft, Hidden Ones

Learning objectives: the hard physical challenges to sustainability and and soft challenges that restrict possible solutions.

Introduction

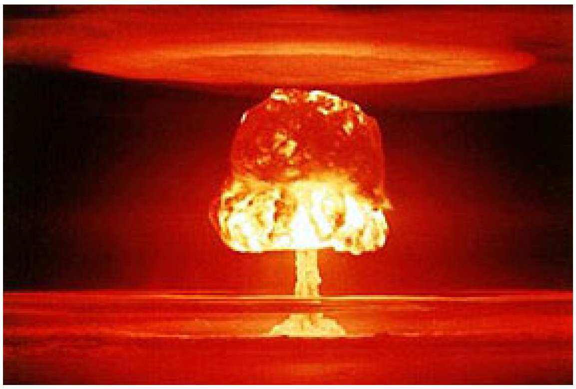
Society faces several hard, physical challenges to sustainability, such as greenhouse warming, nuclear war, fossil fuel exhaustion and pollution. Their physical mechanisms as well as how to physically overcome them are well understood. However, there are soft challenges as well, due to social and indirect physical mechanisms that make overcoming hard challenges even more difficult.

The Hard Challenges

Even though most of us know the "hard", physical challenges faced by society, it is worth reviewing several key challenges.

Global Nuclear War

This one can happen faster than it can be stopped, hence prevention is vital. The world's major nuclear arsenals are ready to be launched upon a moment's notice, resulting in the destruction of humanity and most life on Earth. A global nuclear war can be triggered by merely one leader of the three super-powers having a really bad morning.

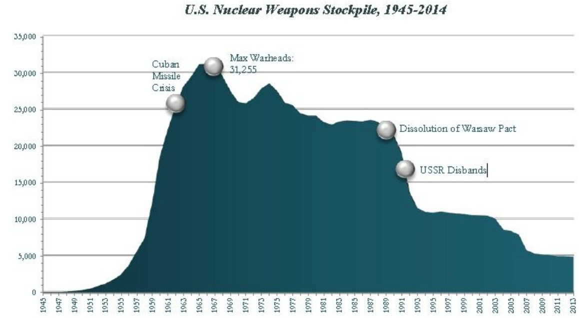


The nuclear blast at Bikini Atoll in 1954
(Photo: Fastfission, Creative Commons)

(Photo credit: U.S. government)

An atomic bomb, such as the one dropped on Hiroshima during World War Two, can wipe out an entire city center. A hydrogen bomb can wipe out an entire state. Many nuclear missiles carry multiple warheads.

- All it takes is one superpower's leader to have a really bad day.
- Risk x consequence?
- A trivial challenge? If it happens, then there is nothing left to worry about?
- So why should we care?

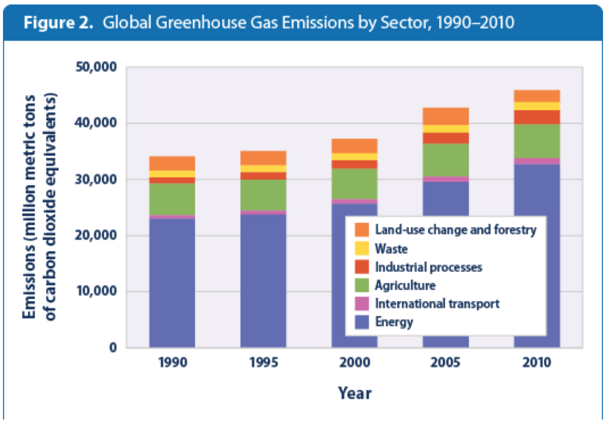


US Nuclear Weapons Stockpile (image credit: U.S. Government)

As of September 2013, the U.S. stockpile of nuclear warheads consisted of 4,804 warheads. This number represents an 85 percent reduction in the stockpile from its maximum (31,255) at the end of fiscal year 1967, and a 78 percent reduction from its level (22,217) when the Berlin Wall fell in late 1989. The below figure shows the U.S. nuclear stockpile from 1945 through September 30, 2013. There are still enough nuclear weapons in existence to totally destroy humanity.

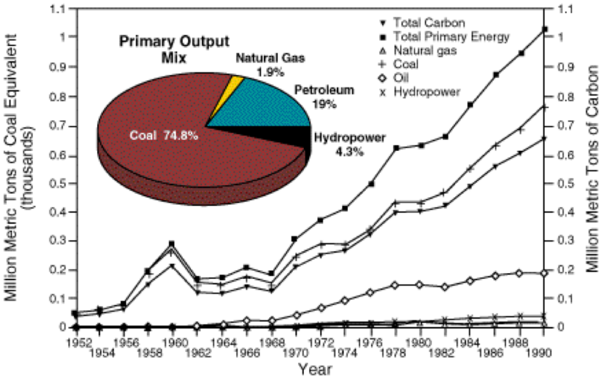
Video of an [atomic bomb explosion](https://www.youtube.com/watch?v=-22tna7KHzI) (https://www.youtube.com/watch?v=-22tna7KHzI).

Climate Change



GHG emissions to 2010 (image credit: U.S. Government)

A potentially exponential killer. The build-up of greenhouse gasses such as carbon dioxide is raising global temperatures thus disrupting many weather- and eco-systems.



- Even worse, this temperature rise can release further greenhouse gasses, possibly resulting in a runaway greenhouse effect, such as on 900 °F Venus.
- Does it matter whether caused by humans? Lightning and forest fire example.

GHG emissions (image credit: U.S. Government)

Environmental destruction

Several aspects of the environment are facing diminishment and destruction.

- Water. Rainfall patterns are changing. Underground reservoirs are being depleted. Human are using more water than some ecosystems can sustainably provide.
- Farmlands. Soil is being eroded. Much prime farmland is being paved over for homes and roads.
- Rainforests, especially in tropical regions such as South America and Southeast Asia, are being cut down for farming. Often these farms are very temporary due to poor soil. The rainforest often does not regrow after its destruction.
- Many species of plants and animals are endangered. When they become extinct, a gap in the eco-system is created, and biodiversity is lost.

Pollution

Pollution covers so many areas that it deserves special mention. Just as humanity can run out of nonrenewable resources, it can create "negative" resources. Often negative resources are disproportionately dangerous. A human needs a lot of food, but can be killed by a tiny amount of poison or biomaterial.

The build-up of toxins and waste in the environment is making parts of the Earth unsuitable for human, animal and plant life. Sources of pollution include:

- Pesticides
- Household chemicals
- Mining waste
- Plastics
- Biohazard waste
- Nuclear waste

Indicators

- Greenhouse gasses
- Toxin readings
- Plastics in ocean
- Rainforest destruction rate

Refugees and Displaced Persons

Each year, millions of people are having to leave their homelands due to violence, poverty, political oppression and climate change.

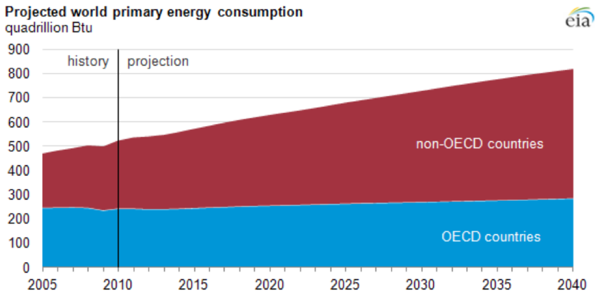
Refugees and displaced persons:

- Adds new capabilities and diversity
- Overwhelms local social bonds and customs

Disruption is a trendy goal these days. Yet is disruption always good for everyone? Do we care?

Energy Supply

The energy supply is sufficient for current use, except that current sources result in tremendous production of greenhouse gasses. Further, the fossil and nuclear fuels upon which our contemporary society depends are nonrenewable.



Energy supply

Hard Challenges As Superficial Challenges?

- Why do we call them superficial?
- What are the root causes of these challenges?

Soft Challenges

Most hard challenges can be overcome is one can overcome the soft challenges behind them.

- Getting people to recognize and accept problems.
- Getting people to take sufficient action
- Trying to get people to work together
- Overcoming effects of game theory
- Hard physical challenges
- Soft physical challenges

4

Introduction to Earth Sciences and Ecology

Earth Sciences

The Earth's ecosystem places a crucial role in sustainability. We breath the air, drink the water and are dependent upon sunlight for food. Therefore it is good to refresh one's memory with a few facts about it. The Earth Sciences (often called Geosciences) include Atmospheric Science (Meteorology), Geology and Oceanography.

Apollo 17 Earth

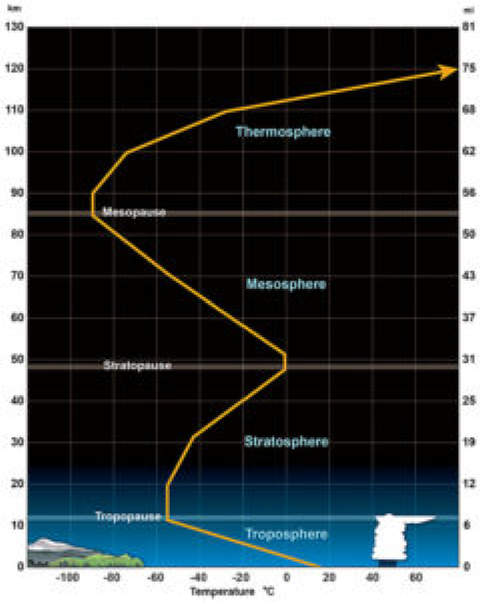
Ecology is the relationships between living organisms and their relationships with the environment.

4.1

Atmospheric Science

Characteristics of the Earth's Atmosphere

The Earth's atmosphere, at its surface, is chiefly composed of 78% Nitrogen, 21% Oxygen (19), 1% Argon and trace amounts of other gasses such as water vapor, carbon dioxide and methane. (Source: NOAA (http://www.srh.noaa.gov/jetstream/atmos/atmos_intro.html)).



Altitude versus temperature of the Earth's atmosphere. Source: NOAA.

The atmosphere is composed of several layers (see figure). The density of the atmosphere decreases with altitude. The *troposphere* is the layer at the Earth's surface and continues up to 10 km. Most cloud formation occurs in they layer. The temperature of the troposphere decreases with altitude up.

Above the troposphere is the *stratosphere*. Its temperature decreases with altitude. Above this, its temperature falls then rises due to other factors such as changing composition.

Surface Temperature and Energy Transport

The atmosphere is warm at the Earth's surface and eventually reaches the cold temperature of space it its top. Heat is transported through the atmosphere by several mechanisms. Some heat is conducted through the atmosphere. Some heat is transported through bulk columns of rising warm air. Other heat is is removed by the action of storms and hurricanes. The amount of energy entering the Earth must be equal to the amount of Energy leaving the Earth over moderately long periods of time.

There are natural variations in surface temperature. The day side of the Earth typically has a lower temperature than the day side. The polar regions exhibit decreasing temperature with latitude and according to season. Surface features such as mountains, oceans and continents can lead to further temperature and weather variations.

Cloud Formation

Cloud formation is of tremendous interest because it has many effects. One effect is to reflect sunlight back into space. Another is to keep heat trapped at the Earth's surface. Clouds can result in rain and are involved in complex weather structures such as tornados and hurricanes.

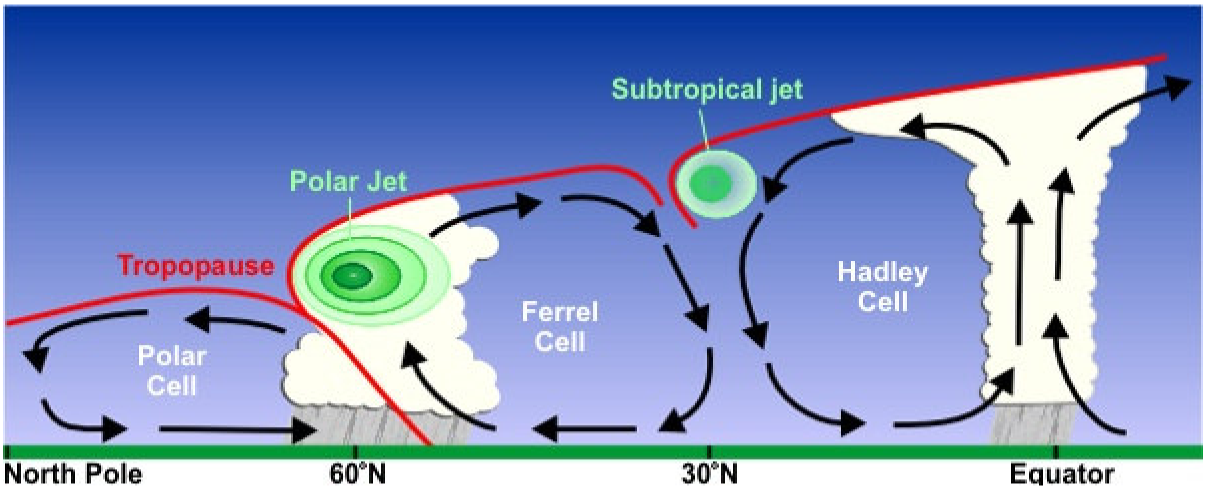
Sunlight causes surface water and moisture to evaporate. Water vapor is less dense than air, so it tends to rise. Since the atmosphere near the surface becomes cooler with altitude, the water vapor will cool and condense, forming clouds. Clouds rise up to about 10 km.

Cloud columns rising on a warm day. Photo credit: NOAA.

Affect of Latitude

An important pattern is vertical air flows versus latitude. At the equator, the atmosphere is at its highest. There is literally an atmospheric bulge about the Equator. Warm, moist air rises high into the atmosphere. Circling the Earth about the Equator is the inter-tropical convergence zone (ITCZ) which is characterized by tall cloud columns and frequent storms (see figure).

Atmospheric cells form in intermediate latitudes. Hadley and Ferrel cells form from the Equator to about 30° latitude north and south. Air rises from the ITCZ, become cool and dry in the upper atmosphere, and then falls to the Earth at about 30°C. This is why many deserts, such as the Sahara, and Australian Outback form at these latitudes. At about 60° north and south, there is another zone of rising air and storm systems.

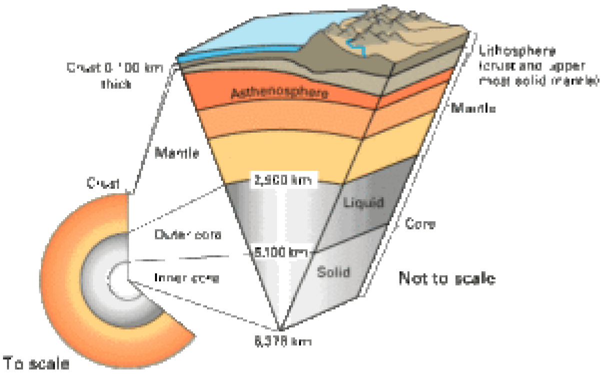


Vertical air flow by latitude and Hadley Cell. Photo credit: *NOAA* (http://www.srh.noaa.gov/jetstream/global/jet.html).

4.2

Geology

Structure of the Earth



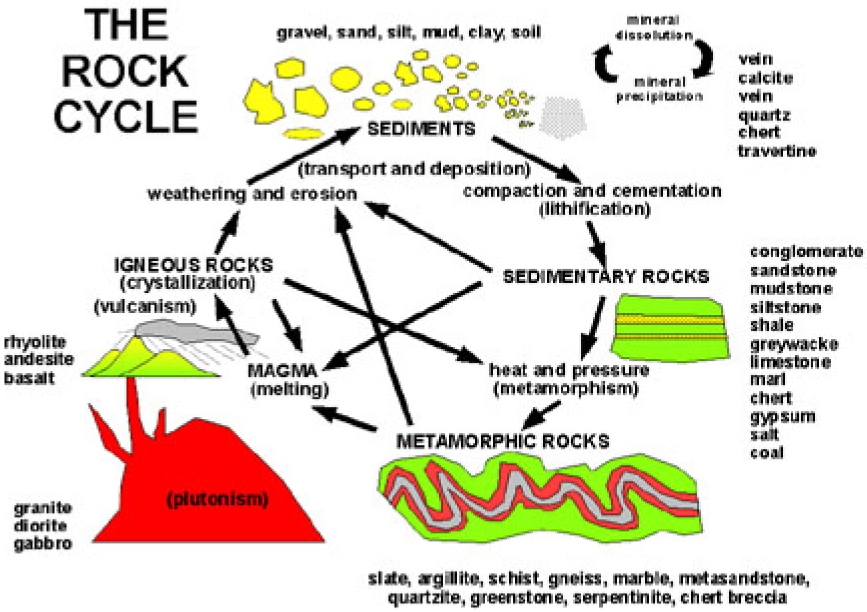
Interior of the Earth. Photo credit: USGS (http://pubs.usgs.gov/gip/dynamic/inside.html).

The Earth is covered with a rocky surface surrounding a hot inner, semi-liquid core. The interior of the Earth is heated by radioactive decay. Upon the interior, large granite continents on tectonic places literally float and drift. Earthquakes can occur where these places grate, drag and overlap each other.

The Rock Cycle

Minerals at the surface initially formed due to volcanic activity. Such are called *igneous* minerals and include quartz, feldspar and basalt. They tend to be quite hard. However, on the surface, the surface breaks up into rocks, which are further worn down by heat, cold and water into sediments such as sands and clays. Such minerals are called *sedimentary* and can form into limestone and shale. If these minerals become trapped under other sediment under high pressure, the grains can attach to each other and form metamorphic minerals, such as quartzite and slate.

When organic matter gets trapped under layers of sediments, fossil fuels such as coal and petroleum can form. Carbon dioxide gets trapped in these fossil fuels until mined and burnt. Limestone also traps much carbon dioxide, until it gets used for concrete.



Rock cycle (credit: U.S. Geological Service)

4.3
Oceanography

Characteristics of the Oceans

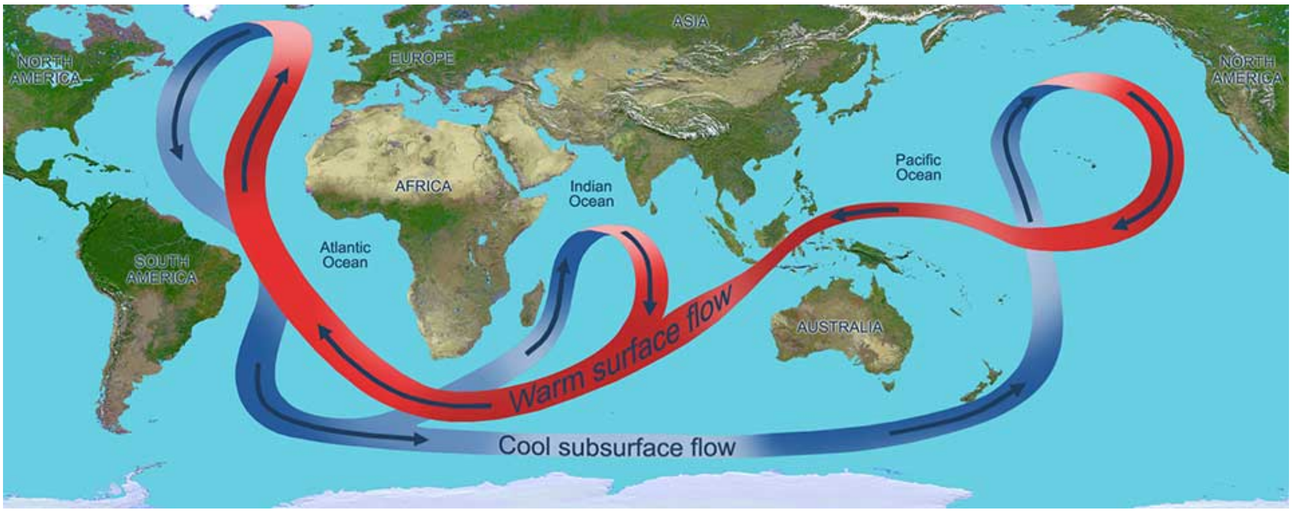
Often overlooked in the geosciences, *Oceanography* concerns the oceans that cover two thirds of the surface of the Earth.

The oceans contain much more than pure water. Many dissolved minerals are present in the water, chiefly sodium chloride (salt). Gasses such as oxygen and carbon dioxide are also present. Most carbon dioxide absorption occurs in the oceans, either consumed by phytoplankton or absorbed into organic matter that often becomes limestone.

The depth of the oceans range from negligible at beaches to several kilometers in deep ocean trenches. Ocean temperatures are dependent upon depth, latitude and also currents.

Currents

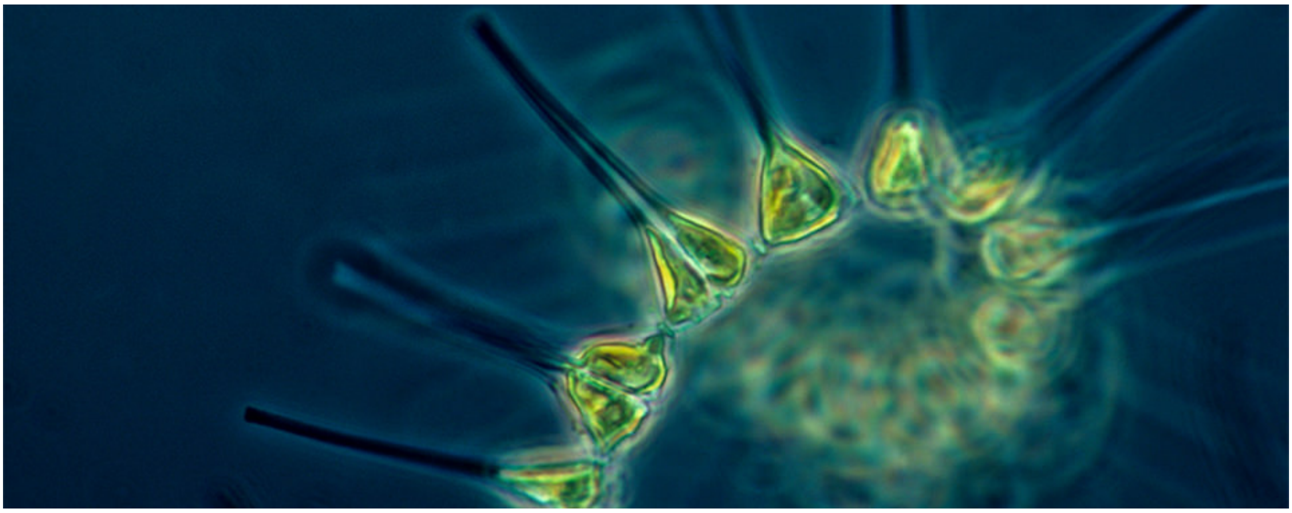
An important topic in oceanography is the major oceanic currents that loop around the continents and affect navigation and climate (see figure).



Warm and cool ocean currents. Photo credit: NOAA.

Life and Pollution

The oceans contain tiny organisms near their surface called *phytoplankton*. These organisms utilize sunlight to convert carbon dioxide into oxygen and other molecules. Without phytoplankton, we would not have vital oxygen to breath. They are also the major source of carbon sequestration.



Phytoplankton (credit: U.S. National Oceanic and Atmospheric Administration)

The oceans contain much other life, such as crustaceans, fish, dolphins and whales, and above the surface, birds. Unfortunately, considerable quantities of pollution and waste also flow into the oceans. Of particular concern is plastic, which gets eaten by the sea creatures who cannot digest it and can die.

Reference

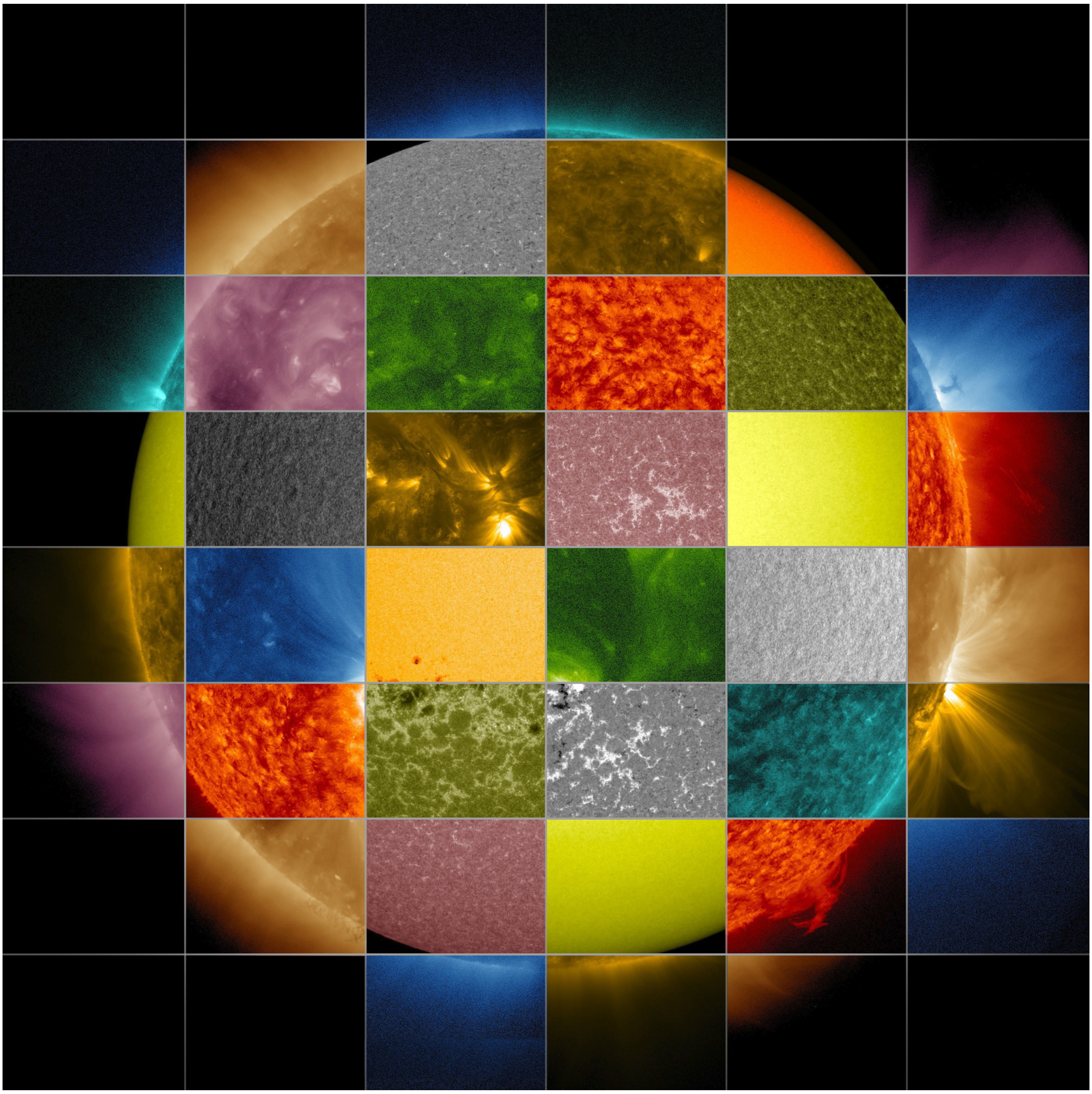
NOAA, http://oceanservice.noaa.gov/facts/phyto.html.

4.4

Energy Balance of the Earth

Sources of Energy

The chief source of energy for the Earth is Sunlight. Gravitational contraction provides a tiny amount. Tidal interactions with the Moon provide a small but significant amount. Radioactive decay provides an important source of energy below the Earth;s surface.



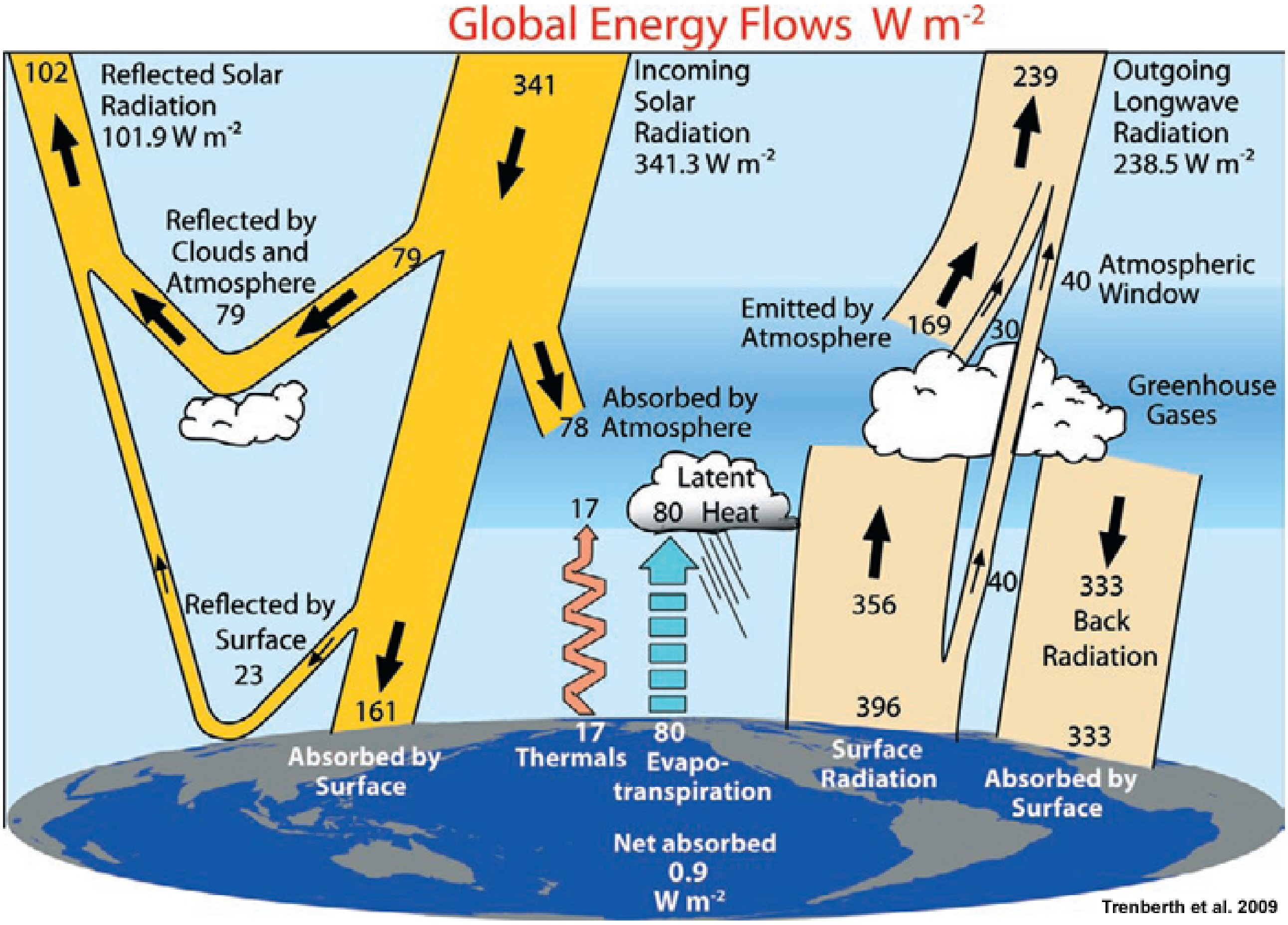
Sun photographed in various wavelengths. (Credit: NASA)

Energy in the Atmosphere

The Earth is bathed in sunlight. Some of that sunlight is reflected back into space by the Earth's surface and atmosphere. The reflectivity of the Earth is called its *albedo*. Some of sunlight directly heats up the atmosphere.

Other sunlight heats up the Earth's surface. As surface temperature becomes raised, the Earth emits increasing amounts of infrared energy. This radiation in turn further heats the atmosphere. Much atmospheric radiation is re-emited to the Earth's surface. Some of it eventually makes it to the upper atmosphere and is radiated back into space.

The amount of energy entering and leaving the Earth;s atmosphere is called its *energy balance*. If more energy enter's the Earth's atmosphere than is emitted, the temperature of the Earth's atmosphere increases. This is the current situation and is called global warming. Climate change results from global warming.



Global energy flows Photo credit: U.S. govt.

4.5
Ecology

Ecology involves the interactions between organisms and their environment.

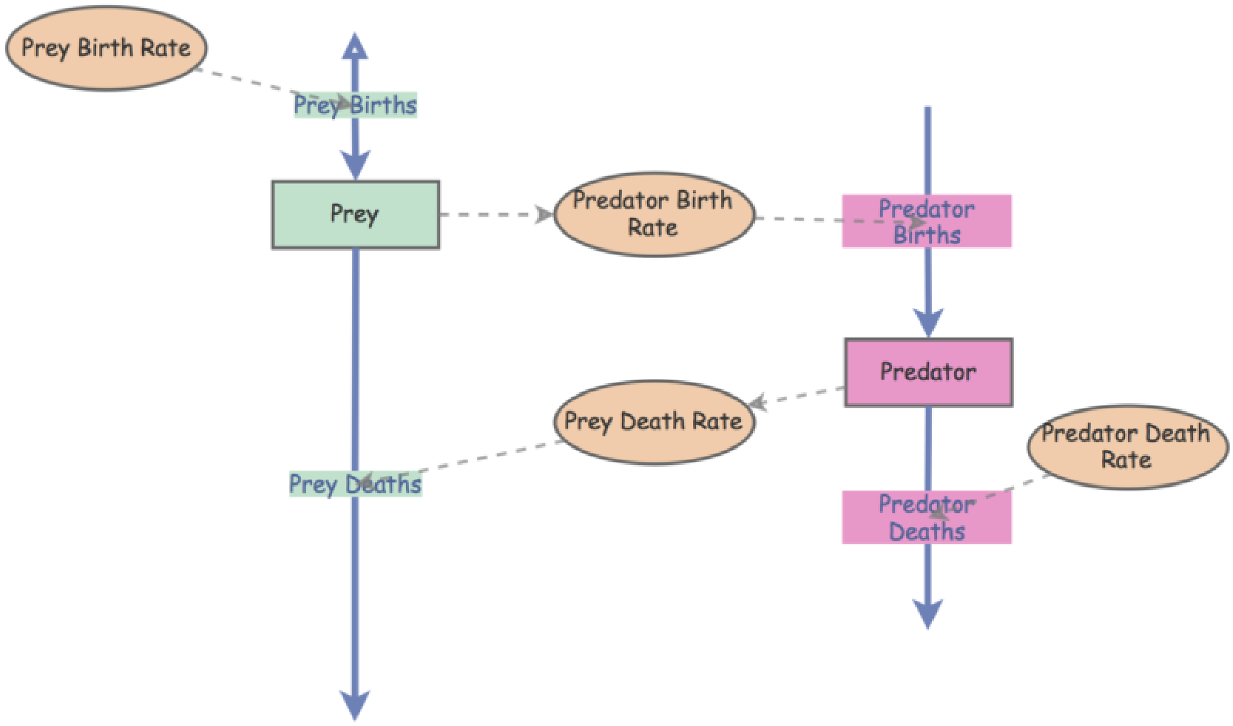
Ecology as a science

There are several important concepts in ecology. Population connects the quantity of a particular organism. It is important because it indicates the magnitude of energy and nutrient flows through an ecological system. It is also a measure of momentum of energy consumption.

Wetlands farming. Plants absorb sunlight and nutrients, then become food for animals. (Photo credit: U.S. government)

Food webs concern the integration between organisms in terms of what they eat and what eats them. Food chains also indicate the flow of energy and nutrients through a system.

Predator-prey relations are an example of components of the food web. See below for an example involving the Lotka-Volterra Predatory-Prey model.



Lotka-Volterra Predatory-Prey model.

5

Energy and Thermodynamics

Introduction

Thermodynamics is a branch of physics that concerns the flow of heat energy and the ability to convert energy into work. Thermodynamics is also extensively used in chemistry, atmospheric science, geology and engineering.

Thermodynamics is a branch of yet a larger branch of physics called statistical mechanics, which brings thermodynamics closer to modern physics. In fact, the discovery of quantum mechanics was an outcrop of thermodynamics. Josiah Williard Gibbs first utilized a quantum approach to express chemical reactions. Max Planck then utilized a quantum approach to express energy levels in photons being edited from a hot object.

Motivation and Applications

An important motivation for thermodynamics was to understand how to make engines more efficient, and what the maximum efficiency for engines could be. Another application is to express the energy involved in chemical reactions.

Popular Definition of Energy

When most people refer to energy, they mean the amount of energy in a substance such as coal or petroleum that can be transformed into useful work. Or for example, they are referring to electric energy such as kiloWatt hours. For example, a liter of gasoline can be combusted to power an automobile to drive uphill for several kilometers.

Physics Definition of Energy

The physics definition of energy includes the popular definition, but it is broader in that it can also refer to energy that cannot be used. For example, ambient heat contains energy. Likewise, there is tremendous nuclear energy contained in the atoms comprising ordinary household objects such as forks and spoons but which cannot be accessed for useful purposes.

- The physics definition of energy E refers to the quantity of motion in a system, or the potential for motion, where m is the mass of an object and v is its velocity.

$$E = \frac{1}{2}mv^2$$

Energy can also refer to stored energy. Energy occurs in several forms:

- Moving objects possess *kinetic* energy
- Batteries, springs and raised objects store *potential* energy
- Randomly-moving molecules represent *heat* energy
- Molecular bonds can store *chemical* energy

Units of Energy

There are several units in which energy can be expressed.

- The standard scientific unit is the Joule, or J.
- A less standard science unit is the Calorie, or cal. One calorie is the amount of energy required to raise one gram of energy by one degree Celsius at standard atmospheric pressure.
- In the USA, the unit for energy in food is also called the Calorie, but the food calorie Cal is equal to 1000 science calories.
- The energy involved in heating systems is often expressed as in terms of the British Thermal Unit, or Btu. One Btu comprises about 1055 Joules.
- Electric energy, such as that delivered to your home, is often expressed in terms of the kilowatt-hour kWh. One Watt, W, is equal to one Joule per second. The Watt is a

unit of power. Multiplying power by time results in an expression of energy.

Photovoltaic panels (source: U.S. Dept. of Energy)

First Law of Thermodynamics

The Law

The First Law of Thermodynamics states that *the total energy of an isolated system shall not change*. In other words, the First Law of Thermodynamics requires that energy can neither be created nor destroyed. In other words, energy is *conserved*. This simply means that if heat flows from one object to another, the quantity of heat leaving the first object must equal the quantity of heat entering the second object.[1]

- Energy can neither be created nor destroyed; in other words, energy is conserved.
- Δ KE + Δ PE + Δ Heat = 0

Discussion

The total energy shall neither increase more decrease. In physics, we say that the energy of an isolated system is *conserved*. (In physics, the term conserved has nothing to do with the environmental term of *conservation*).

What is an isolated system? Not surprisingly, a characteristic of isolated systems is that energy can neither enter or leave them. For example, a perfectly well-insulated container of hot water would be an isolated system. Although that particular hot water system is impossible in real life, it can be fairly well approximated using a reflective vacuum chamber, such as in an old-style coffee thermos. The entire Universe is considered to be an isolated system.

Mixing example

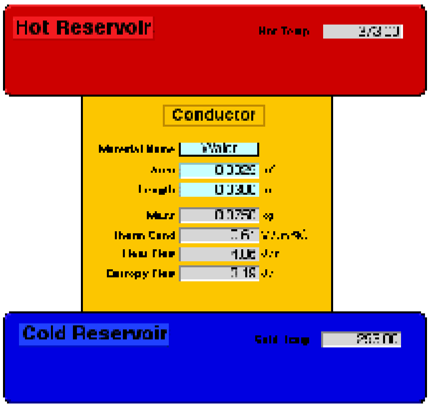
A simple example that demonstrates the First Law is to mix a quantity of cool water with an equal quantity of hot water. If the water is kept in insulated containers before and after the mixing, then the temperature of the final mixture will be the mean of the temperatures of the original constituents (there may be a slight variation due to evaporation or escaped heat). In other words, the total amount of heat energy remained the same despite the mixing and temperature changes.

Conduction example

Another simple example concerns a thermal conductor through which energy flows from a warmer body to a cooler body.

The quantity of heat energy lost by the warmer body is identical to the quantity of heat energy gained by the cooler body. This example can be easily replicated by using a U-shaped aluminum conductor to bridge two well-insulated cups of water of different temperatures.[2] (The conductor should be appropriately insulated as well for best results).

The rate of heat transfer here is known as Newton's Law of Cooling.



Conductor bridging a thermal difference

Conversion of Form of Energy

The First Law allows energy to be converted from one form into another. Consider the case of a swinging pendulum (in a vacuum). As the pendulum bob falls, it will speed up, and its kinetic energy shall consequently increase, while its potential energy (due to gravity) shall decrease. When the bob rises, its potential energy increases at the cost of its kinetic energy. In all cases, though, the total energy remains the same.

$$Total\ Energy = Kinetic\ Energy + Potential\ Energy$$

What if we now have the pendulum operate in air, instead of a vacuum? The pendulum will gradually slow down due to air resistance. The total of potential + kinetic energy shall decrease! However, according to the First Law, the energy must go somewhere. It cannot merely disappear. As friction continues to operate and the pendulum continues to hit air molecules, the average (mean) velocity of the individual air molecules increases. So the air heats up a bit, and the pendulum's energy is gradually transferred into heat energy. Eventually, the motion of the pendulum will stop, but energy in the air will have increased, as exhibited by an increased air temperature.

$$Total\ Energy = Kinetic\ Energy + Potential\ Energy + Thermal\ Energy$$

Modern Physics Modification

Who has not heard of Albert Einstein's famous equation $E = mc^2$? Energy can be changed into mass and vice-versus. So the First Law must be modified to take into account this mass-energy equivalence. This is the realm of nuclear reactors and nuclear bombs, and its effect is insignificant on most systems we encounter in our lives.

Resources

- Paper (http://www.heatsuite.com/wp-content/uploads/2014/12/Newtons_Law_of_Cooling.pdf) concerning Newton's Law of Cooling and a simulation.
- Newton's Law of Cooling simulation (http://www.heatsuite.com/?page_id=64).
- Newton's Law of Cooling program code (https://github.com/mciotola/newtons_law_of_cooling_analytical).

Notes & References

[1] The phrase "conservation *of* energy" has a much different meaning than the common phrase "*conserving energy*". The latter refers to consuming less of *useful forms* of energy such as coal or petroleum.

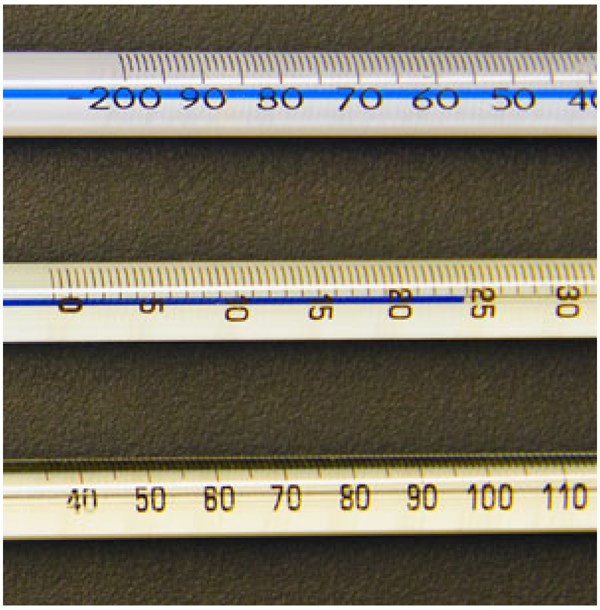
Temperature

Introduction

Recall that one form of energy is thermal energy, which comprises the random motion of individual molecules that are part of a larger system. For example, water molecules in a tea kettle are moving back and forth in all directions and at many different speeds. Some water molecules might be moving slowly, and they would have a lower energy than those that are moving quickly.

Temperature refers to the intensity of thermal energy. Regardless of the energy of individual molecules, if their average (mean) velocity is high, then the temperature of the collection of those molecules is high. The the average is low, then the temperature is low.

Measuring Temperature



Analog thermometers (source: U.S. govt.)

One cannot easily measure the individual velocities of molecules within a large collection of such. Fortunately, there exists easier ways to measure temperature. The traditional device for measuring temperature is the thermometer. Thermometers can operate by measuring the expansion of a fluid such as mercury or alcohol. Other thermometers operate by comparing the expansion on one metal to another.

More modern devices can measure temperature by detecting infrared radiation emitted from an object. Such devices only measure surface temperature, but adjustments can be made to infer the internal temperature of an object such as a human.

Units of Temperature

Temperature measuring devices (source: U.S. government)

- In the USA, the degree Fahrenheit, F, is used to express temperature.
- In the metric system, the degree Celsius (or Centigrade) expresses temperature.
- The preferred unit by physicists is the Kelvin, K. One unit of Kelvin is equal to one degree Celsius, except that the Kelvin system starts at absolute zero temperature. 0 degrees Celsius is equal to 273.15 Kelvin.

Second Law of Thermodynamics

The Law

The Second Law of Thermodynamics states that *a quantity called entropy can never decrease for an isolated system*.

- 2nd Law: Entropy of an isolated system cannot decrease.
- $fracdSdt \geq 0$

Definition of Entropy

With the advent of modern physics, the term entropy$S$ has a precise definition. It is Boltzmann's constant $k$multiplied by the log of multiplicity $Omega$. Further explanation is in order.

$$Boltzmann's\ constant = k = 1.381x10^{-23} m^2\ kg\ s^{-2}.$$

$$Entropy = kOmega.$$

Multiplicity

Multiplicity is the number of ways a state can be produced in a given system. For example, in a system of three US pennies, a state comprising two heads can be comprised three ways (where H = heads and T = tails):

Coin 1	Coin 2	Coin 3
H	H	T
H	T	H
T	H	H

A Few More Points

For entropy calculations, we are typically considering how the instances of energy can be arranged, but types of particles also have an effect.

It is important to note that the Second Law does not prohibit the entropy of a system from increasing.

Conduction Example Revisited

Recall our example of a conductor bridging warmer and cooler bodies. If heat flows from the warmer body to the cooler body, then the total entropy of this system increases. Entropy of a particular body increases as the body's temperature increases. So if the warmer body's temperature decreases as it loses heat energy, then its entropy will decrease. However, according to the First Law of Thermodynamics, any heat lost by one body must be gained by another body. In this example, the heat lost by the warmer body is gained by the cooler body. The magnitude of the entropy increase of the cooler body is greater than the magnitude of entropy loss by the warmer body, so the total entropy of the combined warm body-cold body system increases.

Ways Entropy Increases

There are commonly several situations where entropy increases. When heat flows result in no work, or less than the Carnot ideal, entropy increases. Many chemical reactions result in increases of entropy, such as when gasoline is combusted to propel an automobile. Entropy is increased when substances become more mixed even where no chemical reaction occurs, such as when helium and neon gasses become mixed together.

Cosmological Perspective

The Second Law requires that the total entropy of the universe must increase over time.[7] Yet, the expansion of the universe result in *decreasing*, not increasing, mean entropy density of the universe. These two trends are not inconsistent. Total entropy of the universe is indeed increasing, but it is being spread out more quickly than it increases.[8]

Yet, locally, gravity pulls together matter and produces local regions of higher entropy such as stars and planets. So really, there are several contrasting trends. The total entropy of the universe increases. Yet as the universe expands, the mean entropy density decreases. Nevertheless, locally, gravity may result in local clumps of high entropy. Then, eventually the entropy of those clumps dissipates into the surrounding universe.

Notes & References

[2] Such demonstration kits are commonly sold by science education equipment firms. If ice water is used, then energy due to the phase change of melting ice must also be accounted for.

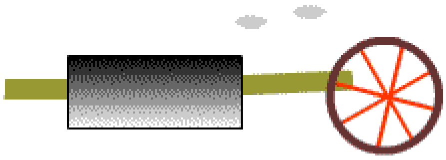
[7] Such a trend extrapolated into the distant suggests that the universe will die a classic heat death, in which no work or life is possible.

[8] As long as this continues to be the case, reports of the universe's impending heat death may be greatly exaggerated, or at least further off than once thought.

Heat Engines

Introduction

A common example used to illustrate the Second Law of Thermodynamics is the Heat Engine. A heat engine is a device that utilizes a temperature difference (*a potential*) to perform work.

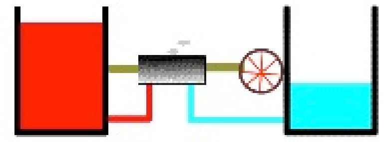


How A Heat Engine Functions

To drive a heat engine to function, heat must flow across a temperature difference,[1] from a warmer region to a cooler one. The warmer region is typically called a hot reservoir (regardless of its actual temperature) with temperature T_h, while the cooler region is designated as the cold reservoir with temperature T_c.

Example

An example is the temperature difference between a hot flame and a cool tank of water being used in a steam engine. When heat flows to power a heat engine, part of the available energy is put into work and the remainder results in waste heat.



Efficiency

No engine turns *all* of the heat flow into work. That would imply 100% efficiency, which is impossible *IN THEORY* as well as practice, regardless of how well the engine is constructed. The Second Law of Thermodynamics tells that even the best engines will produce entropy along with work. The best efficiency that an ideal engine can achieve is known as its Carnot Efficiency. The Carnot Efficiency is simply the difference between the warmer and cooler temperature divided by the warmer temperature. In reality, most engines are a great deal less efficient than even the Carnot efficiency. Several modern means exist to utilize higher order energy.

Equation for Carnot Efficiency

The efficiency of a Carnot Engine depends upon the temperature difference between the thermal reservoirs, where the temperature f the hot reservoir is Th and that of the cold reservoir is Tc. The the Carnot~Efficiency is:

$$epsilon = 1 - fracT_cT_h$$

Calculating the Carnot Efficiency must be done using absolute temperatures, that is, temperatures measured from absolute zero. Absolute zero is the lowest possible temperature in theory, and has never been quite obtained in practice. Such temperatures are measured in a kind of degree called Kelvin. 0° Celsius equals about 273.15 Kelvin.

An example is the temperature difference between a hot flame and a cool tank of water being used in a steam engine. Then, part of the available energy is used to perform work and the remainder is exhausted as waste heat. For instance, a steam engine could contain a piston that converts some of the heat flow into a cyclic in-out motion that represents work done upon a load, such as a flywheel wheel. Steam released into cooler air represents waste heat. When waste heat is created, an intangible quantity called entropy is produced. The more the heat engine works, the more entropy it will produce.[2]

Work Performed by a Carnot Engine

If an amount of heat Q_h is removed from the hot reservoir, the the amount of work W a Carnot engine will perform is

$$W = epsilonQ_h.$$

Work Performed by Real Life Heat Engines

While a Carnot Engine can be approximated in real life, despite its high efficiency, it functions too slowly to be of much value for real life uses. Ironically, practical heat engines tend to operate of much lower efficiencies. This real life efficiency is called "Second Law Efficiency", $epsilon_s$.

$$epsilon_{second\ law} leqepsilon_{Carnot}.$$

Further Discussion

If heat flows from a warmer object to a cooler object (where no engine is involved), no work results, but entropy is still produced (or you could say that the entropy of the system under consideration increases). Thermal conduction itself results in lots of entropy production but little work. A thermal conductor can be thought of as a lazy heat engine. Chemical reactions, such as burning coal and oil or metabolizing sugars also results in entropy production. The Second Law of Thermodynamics states that overall entropy (of an entire system) will tend to increase.

Notes & References

[1] Incidentally, a heat engine is a system that has pure physical aspects as well as social aspects.

[2] In theory, a heat engine is not required to produce entropy if the temperature of the cold region is absolute zero (which is about - 273° C). In practice, such a low temperature is physically impossible.

5.1
Introduction to Energy

Popular Definition of Energy

When most people refer to energy, they mean the amount of energy in a substance such as coal or petroleum that can be transformed into useful work. For example, a liter of gasoline can be combusted to power an automobile to drive uphill for several kilometers. Or, they are referring to electric energy, which can likewise be used to perform work..

Physics Definition of Energy

The physics definition of energy includes the popular definition, but it is broader. In physics, energy can also refer to such that cannot be used but is nevertheless present. For example, ambient heat contains energy. Likewise, there is tremendous nuclear energy contained in the atoms comprising ordinary household objects such as forks and spoons but which cannot be accessed for useful purposes.

- The physics definition of energy E refers to the quantity of motion in a system, or the potential for motion, where m is the mass of an object and v is its velocity.

$$E = \frac{1}{2}mv^2$$

Energy can also refer to stored energy. Energy occurs in several forms:

- Moving objects possess *kinetic* energy
- Batteries, springs and raised objects store *potential* energy
- Randomly-moving molecules represent *heat* energy
- Molecular bonds can store *chemical* energy
- Atomic nuclei can store *nuclear* energy

Units of Energy

There are several units in which energy can be expressed.

- The standard scientific unit is the *Joule*, or J.
- A less standard science unit is the *Calorie*, or cal. One calorie is the amount of energy required to raise one gram of water by one degree Celsius at standard atmospheric pressure.
- In the USA, the unit for energy in food is also called the Calorie, but the food calorie Cal is equal to 1000 science calories.
- The energy involved in heating systems is often expressed as in terms of the British Thermal Unit, or Btu. One Btu comprises about 1055 Joules.
- Electric energy, such as that delivered to your home, is often expressed in terms of the kilowatt-hour kWh. One Watt, W, is equal to one Joule per second. The Watt is a unit of power. Multiplying power by time results in an expression of energy.

Photovoltaic panels (source: U.S. Dept. of Energy)

5.2
Thermodynamics

Introduction

Thermodynamics is a branch of physics that concerns the flow of heat energy and the ability to convert energy into work. Thermodynamics is extensively used in chemistry, atmospheric science, geology and engineering.

Thermodynamics is part of a yet larger branch of physics called statistical mechanics, which bridges thermodynamics with modern physics. In fact, the discovery of quantum mechanics was an outcrop of thermodynamics. Josiah Williard Gibbs first utilized a quantum approach to express chemical reactions. Max Planck then utilized a quantum approach to express energy levels in photons being edited from a hot object.

Motivation and Applications

An important motivation for development of thermodynamics as a discipline was to understand how to make engines more efficient, and what the maximum efficiency for engines could be. Another application was to express the energy involved in chemical reactions.

5.3
First Law of Thermodynamics

The Law

The First Law of Thermodynamics states that *the total energy of an isolated system shall not change*. In other words, the First Law of Thermodynamics requires that energy can neither be created nor destroyed. In other words, energy is *conserved*. This simply means that if heat flows from one object to another, the quantity of heat leaving the first object must equal the quantity of heat entering the second object.[1]

> Energy can neither be created nor destroyed; in other words, energy is conserved.

Discussion

The total energy shall neither increase more decrease. In physics, we say that the energy of an isolated system is *conserved*. (In physics, the term conserved has nothing to do with the environmental term of *conservation*).

What is an isolated system? Not surprisingly, a characteristic of isolated systems is that energy can neither enter or leave them. For example, a perfectly well-insulated container of hot water would be an isolated system. Although that particular hot water system is impossible in real life, it can be fairly well approximated using a reflective vacuum chamber, such as in an old-style coffee thermos. The entire Universe is considered to be an isolated system.

Mixing example

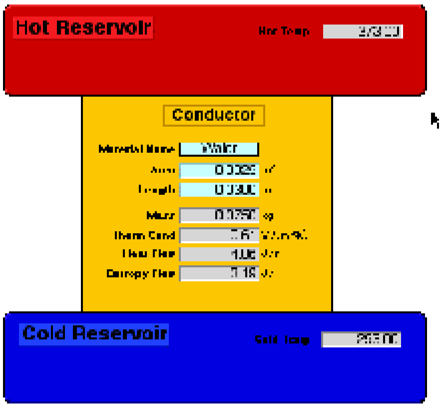
A simple example that demonstrates the First Law is to mix a quantity of cool water with an equal quantity of hot water. If the water is kept in insulated containers before and after the mixing, then the temperature of the final mixture will be the mean of the temperatures of the original constituents (there may be a slight variation due to evaporation or escaped heat). In other words, the total amount of heat energy remained the same despite the mixing and temperature changes.

Conduction example

Another simple example concerns a thermal conductor through which energy flows from a warmer body to a cooler body.

The quantity of heat energy lost by the warmer body is identical to the quantity of heat energy gained by the cooler body. This example can be easily replicated by using a U-shaped aluminum conductor to bridge two well-insulated cups of water of different temperatures.[2] (The conductor should be appropriately insulated as well for best results).

The rate of heat transfer here is known as Newton's Law of Cooling.



Conductor bridging a thermal difference

Conversion of Form of Energy

The First Law allows energy to be transformed from one form into another, such as from potential to kinetic energy. Yet the total amount of energy must remain the same.

Consider the case of a swinging pendulum (in a vacuum). As the pendulum bob falls, it will speed up, and its kinetic energy shall consequently increase, while its potential energy (due to gravity) shall decrease. When the bob rises, its potential energy increases at the cost of its kinetic energy. In all cases, though, the total energy remains the same.

$$Total\ Energy = Kinetic\ Energy + Potential\ Energy + Heat\ Energy$$

Likewise,

$$\Delta\ \mathrm{KE} + \Delta\ \mathrm{PE} + \Delta\ \mathrm{Heat} = 0$$

What if we now have the pendulum operate in air, instead of a vacuum? The pendulum will gradually slow down due to air resistance. The total of potential + kinetic energy shall decrease! However, according to the First Law, the energy must go somewhere. It cannot merely disappear. As friction continues to operate and the pendulum continues to hit air molecules, the average (mean) velocity of the individual air molecules increases. So the air heats up a bit, and the pendulum's energy is gradually transferred into heat energy. Eventually, the motion of the pendulum will stop, but energy in the air will have increased, as exhibited by an increased air temperature.

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Modern Physics Modification

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Resources

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Notes & References

[1] The phrase "conservation *of* energy" has a much different meaning than the common phrase "*conserving energy*". The latter refers to consuming less of *useful forms* of energy such as coal or petroleum.

5.4

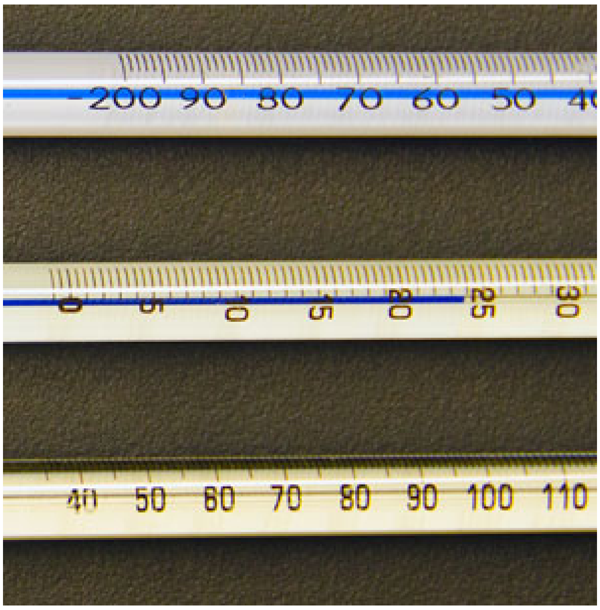
Temperature

Introduction

Recall that one form of energy is thermal energy, which comprises the random motion of individual molecules that are part of a larger system. For example, water molecules in a tea kettle are moving back and forth in all directions and at many different speeds. Some water molecules might be moving slowly, and they would have a lower energy than those that are moving quickly.

Temperature refers to the intensity of thermal energy. Regardless of the energy of individual molecules, if their average (mean) velocity is high, then the temperature of the collection of those molecules is high. The the average is low, then the temperature is low.

Measuring Temperature



Analog thermometers (source: U.S. govt.)

One cannot easily measure the individual velocities of molecules within a large collection of such. Fortunately, there exists easier ways to measure temperature. The traditional device for measuring temperature is the thermometer. Thermometers can operate by measuring the expansion of a fluid such as mercury or alcohol. Other thermometers operate by comparing the expansion on one metal to another.

More modern devices can measure temperature by detecting infrared radiation emitted from an object. Such devices only measure surface temperature, but adjustments can be made to infer the internal temperature of an object such as a human.

Units of Temperature

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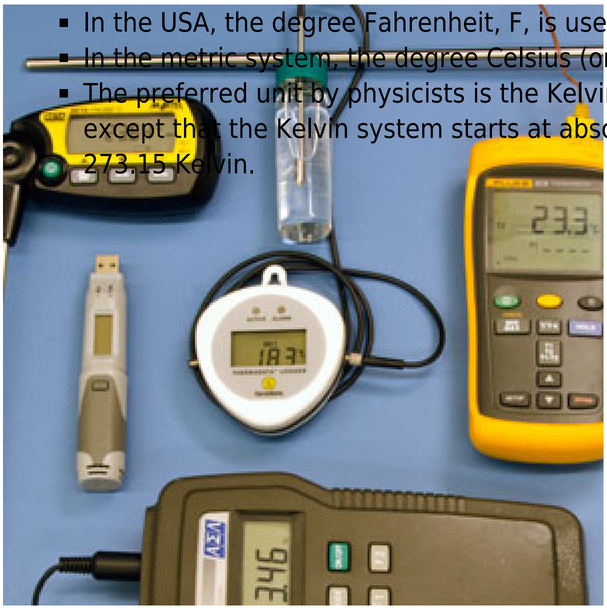


Temperature measuring devices (source: U.S. government)

5.5
Second Law of Thermodynamics

The Law

The Second Law of Thermodynamics states that *a quantity called entropy can never decrease for an isolated system*.

- 2nd Law: Entropy of an isolated system cannot decrease.
- $\frac{dS}{dt} \geq 0$

Definition of Entropy

With the advent of modern physics, the term entropy S has a precise definition. It is Boltzmann's constant k multiplied by the log of multiplicity Ω. Further explanation is in order.

$$Boltzmann's\ constant = k = 1.381x10^{-23}m^2\ kg\ s^{-2}.$$

$$Entropy = k\Omega.$$

Multiplicity

Multiplicity is the number of ways a state can be produced in a given system. For example, in a system of three US pennies, a state comprising two heads can be comprised three ways (where H = heads and T = tails):

Coin 1	Coin 2	Coin 3
H	H	T
H	T	H
T	H	H

A Few More Points

For entropy calculations, we are typically considering how the instances of energy can be arranged, but types of particles also have an effect.

It is important to note that the Second Law does not prohibit the entropy of a system from increasing.

Conduction Example Revisited

Recall our example of a conductor bridging warmer and cooler bodies. If heat flows from the warmer body to the cooler body, then the total entropy of this system increases. Entropy of a particular body increases as the body's temperature increases. So if the warmer body's temperature decreases as it loses heat energy, then its entropy will decrease. However, according to the First Law of Thermodynamics, any heat lost by one body must be gained by another body. In this example, the heat lost by the warmer body is gained by the cooler body. The magnitude of the entropy increase of the cooler body is greater than the magnitude of entropy loss by the warmer body, so the total entropy of the combined warm body-cold body system increases.

Ways Entropy Increases

There are commonly several situations where entropy increases. When heat flows result in no work, or less than the Carnot ideal, entropy increases. Many chemical reactions result in increases of entropy, such as when gasoline is combusted to propel an automobile. Entropy is increased when substances become more mixed even where no chemical reaction occurs, such as when helium and neon gasses become mixed together.

Cosmological Perspective

The Second Law requires that the total entropy of the universe must increase over time.[7] Yet, the expansion of the universe result in *decreasing*, not increasing, mean entropy density of the universe. These two trends are not inconsistent. Total entropy of the universe is indeed increasing, but it is being spread out more quickly than it increases.[8]

Yet, locally, gravity pulls together matter and produces local regions of higher entropy such as stars and planets. So really, there are several contrasting trends. The total entropy of the universe increases. Yet as the universe expands, the mean entropy density decreases. Nevertheless, locally, gravity may result in local clumps of high entropy. Then, eventually the entropy of those clumps dissipates into the surrounding universe.

Notes & References

[2] Such demonstration kits are commonly sold by science education equipment firms. If ice water is used, then energy due to the phase change of melting ice must also be accounted for.

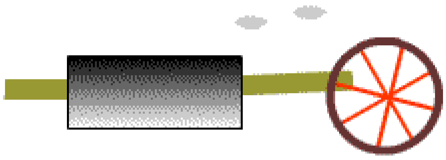
[7] Such a trend extrapolated into the distant suggests that the universe will die a classic heat death, in which no work or life is possible.

[8] As long as this continues to be the case, reports of the universe's impending heat death may be greatly exaggerated, or at least further off than once thought.

5.6
Heat Engines

Introduction

The *heat engine is a* common example used to illustrate the Second Law of Thermodynamics. A heat engine utilizes a temperature difference (*a thermodynamic potential*) to perform work, such as moving a train or pumping water.

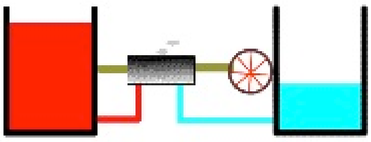


How A Heat Engine Functions

For a heat engine to function, heat must flow across a temperature difference from a warmer region to a cooler one. The warmer region is typically called a hot reservoir (regardless of its actual temperature) with temperature T_h, while the cooler region is designated as the cold reservoir with temperature T_c. A typical heat engine undergoes a cycle of actions where heat flows into the engine, increases pressure of a fluid such as air or steam, used that pressure to push a piston, then releases the heat whereupon pressure is reduced. [1]

Example

An example is the temperature difference between a hot flame and a cool tank of water being used in a steam engine. When heat flows to power a heat engine, part of the available energy is put into work and the remainder results in waste heat. Below, the lefthand red area represents the hot reservoir, and the righthand blue area represents the cold reservoir. The gray area represents the engine. Heat flows through the engine, which does work by turning a wheel, which might drive a generator, push a car or run a machine tool.



Efficiency

No engine turns *all* of the heat flow into work. That would imply 100% efficiency, which is impossible *in* *theory* as well as practice, regardless of how well the engine is constructed. The Second Law of Thermodynamics tells that even the best engines will produce entropy along with work. Efficiency ϵcan be expressed as:

$$\epsilon = \frac{heat\ flow - work}{heat\ flow}$$

Carnot Efficiency

The best efficiency that an ideal engine can achieve is known as its *Carnot Efficiency*. The efficiency of a Carnot Engine depends upon the temperature difference between the thermal reservoirs, where the temperature of the hot reservoir is T_h and that of the cold reservoir is T_c. The Carnot Efficiency ϵ_c is simply the difference between the warmer and cooler temperature divided by the warmer temperature:

$$\epsilon_c = 1 - \frac{T_c}{T_h}$$

Calculating the Carnot Efficiency must be done using absolute temperatures, that is, temperatures measured from absolute zero. Absolute zero is the lowest possible temperature in theory, and has never been quite obtained in practice. Such temperatures are measured in a kind of degree called Kelvin. 0° Celsius equals about 273.15 Kelvin.

An example is the temperature difference between a hot flame and a cool tank of water being used in a steam engine. Then, part of the available energy is used to perform work and the remainder is exhausted as waste heat. For instance, a steam engine could contain a piston that converts some of the heat flow into a cyclic in-out motion that represents work done upon a load, such as a flywheel wheel. Steam released into cooler air represents waste heat. When waste heat is created, an intangible quantity called entropy is produced. The more the heat engine works, the more entropy it will produce.[2]

Work Performed by a Carnot Engine

If an amount of heat Q_h is removed from the hot reservoir, the the amount of work W a Carnot engine will perform is

$$W = \epsilon Q_h\,.$$

Work Performed by Real Life Heat Engines

In reality, most engines are a great deal less efficient than even the Carnot efficiency. While a Carnot Engine can be approximated in real life, despite its high efficiency, it functions too slowly to be of much value for real life uses. Practical heat engines tend to operate of much lower efficiencies. This real life efficiency is called "Second Law Efficiency", ϵ_s.

$$\epsilon_{second\ law} \leq \epsilon_{Carnot}.$$

One reason that engines operate at lower efficiencies than better construction would allow is that more efficient heat engines tend to take more resources to build.

Further Discussion

If heat flows from a warmer object to a cooler object (where no engine is involved), no work results, but entropy is still produced (or you could say that the entropy of the system under consideration increases). Thermal conduction itself results in lots of entropy production but little work. A thermal conductor can be thought of as a lazy heat engine. Chemical reactions, such as burning coal and oil or metabolizing sugars also results in entropy production. The Second Law of Thermodynamics states that overall entropy (of an entire system) will tend to increase.

Notes & References

[1] For the origins of heat engine theory, read the works of Sadi Carnot.

[2] In theory, a heat engine is not required to produce entropy if the temperature of the cold region is absolute zero (which is about - 273° C). In practice, such a low temperature is physically impossible.

6
Unified Science

Benefits

A major goal of Big Sustainability is to develop a unified science. A unified science would will offer several major benefits.

1. It would allow a wide range of phenomena to be studied and understood using the same principles.
2. It will allow experts from different fields to more effectively communicate with each other. This would make it easier to understand and analyze the big picture.
3. It will better enable systematic thinking by capturing more parts of the system and understanding how they relate to each other, identifying interdependencies.
4. as well as to develop comprehensive expressions for the state of the entire system, allowing of more effective global optimization.

The beginnings of a unified science are discussed here. There are several concepts that are interrelated and have broad applications.

Characteristics

Characteristics of such a science are unifying principles and terminology.

For example, a potential can refer to a physical or a social potential.

Terminology and Principles

- *Achievement* is progress towards some goal of an individual or system. In physics, achievement can be called work. In economics, achievement can be called production or profit.
- A *potential* is the possibility to achieve. In economics, the consumption of potential is called revenue.
- An *engine* represents a means to transform potential into achievement.
- A *flow* is the progression or transfer of quantities within or to the outside of a system.
- *Efficiency* is the proportion of consumption that becomes transformed into production (achievement).
- *Waste* is is the proportion of potential consumed that does *not* become transformed into achievement.
- *Equilibrium* is the eventual end state of any isolated system. All the potential has

been achieved.
- *Dynamic equilibrium* is when consumption is balanced with the relevant flow.

These concepts can be used to express and analyze a broad range of situations.

7

The Small

Introduction

The Small concerns individuals and small communities. The Small can be summed up with the first-person pronoun "I". It can be viewed as the inner perspective. Each individual person comprises a unique combination of characteristics. Each person exists in an information-rich environment about oneself.

Each human has their own consciousness, perspective, drive and a unique configuration of needs. Each human perceives information and interprets it in a highly-individual manner. Each human receives information about their own situation to which only they may have access. Hence each human has their own interests.

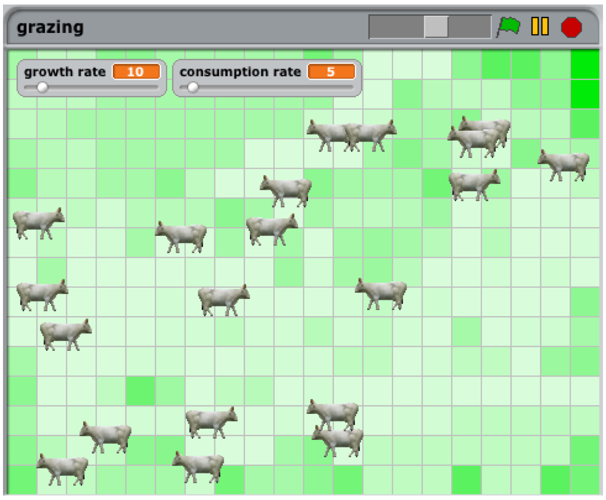
Each human, or small group of humans, tends to act to maximize their interests (what the economists call "utility")

It is easier for one to gain leverage over one's local situation. Therefore focusing on the Small is very attractive, and often more immediately rewarding and lower risk. One can have more direct control over the Small.

Small Is Beautiful

In an era of globalization, there is tendency to try to refocus on the small. The Small emphasis was kicked off in the 1970s, perhaps best characterized by the 1973 book by Fritz Schumacher called *Small is Beautiful*. (Also see: *Small Is Beautiful, 25th Anniversary Edition: Economics As If People Mattered*, 1989). Recently, there is a push to purchase produce from local farmers.

The Small-Agent-Based Systems

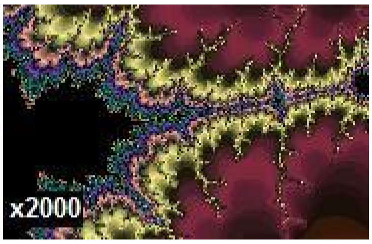


Agent-based system featuring grazing cows (source: Monash University)

A system can be modeled as a collection of independently-acting players or "agents". Such agent-based models are well suited for bottom-up approaches.

An "Agent" in computer science or complex systems talk can be an individual organism, such as a person or cow or a small firm.

Emergence and Self-Organizing Systems



Mandelbrot fractal

Complex structures can emerge out of agent-based systems. Such systems are called self-organizing systems. Fractals are an example.

The Goal of the Small

The goal of the small is local optimization. For example, a small firm would attempt to maximize its own profits rather than those of its entire industry or economy.

Living Organisms

The small includes individual living organisms as well as small, local ecosystems. Examples include microbes, plants, fish, reptiles, mice, dogs, cats, and humans.

Consciousness

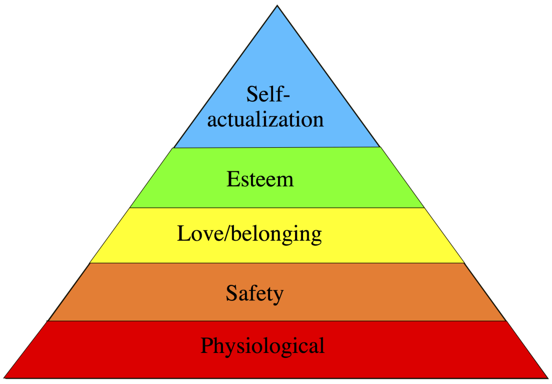
- What is consciousness?
- Do we have consciousness?

DIY Psychology

- Responses, reactions

Maslow's Hierarchy of Needs

Our current needs depend upon what we already have. For example, we tend not to focus on love/belonging until we are fed and safe (exceptions exist).



Maslows Hierarchy Of Needs

Position on the EDEG Curve

- Often our psychological state of mind is a function of our position on an EDEG curve.
- We literally move up and down on Maslow's Hierarchy depending on whether we are on rising or falling positions.

Reaction to Function Positions

Populations may exhibit group reactions to positions and changes of position on large-scale functions.

Tools

There are several useful tools for simulating the Small.

- Cellular (http://aidanlane.github.io/snapapps/cellular.html) for agent-based, cellular automata simulations

8

The Big

Perspective of The Big

- "They"
- Outer Perspective
- An entire system that embodies all of its interrelated components.
- A nation, a continent, a world.
- Top-down approaches.

The Goal of the Big

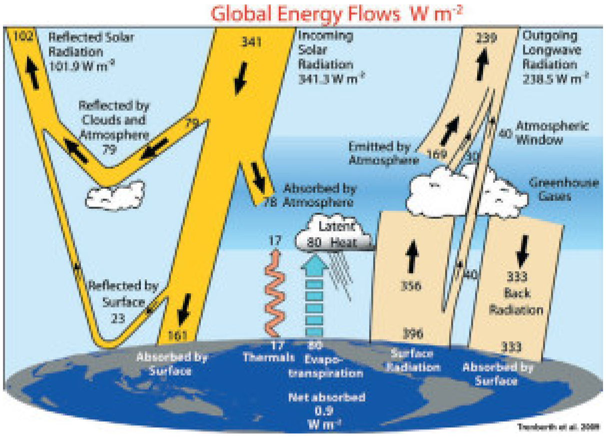
- Global optimization
- A global optimum is the maximum achievement of a goal for an entire system, rather than for any of its individual components or subsystems (e.g. local optima).

The Big-System Dynamics

- System dynamics is simulating the progression over time of a process involving multiple, interacting components.
- Initially developed by J. Forrester at MIT in the mid-1950s.
- Widely used to model industrial processes.
- Used to model the progression of the world, and its economy and environment by the Club of Rome study *Limits to Growth* (1972).

Climate Change

Climate change is a challenge that most experts agree must be handled through global cooperation and constraints.



Tools

There are several useful tools for simulating the Big.

- Insightmaker (http://Insightmaker) system dynamics simulations. (https://www.r-project.org)
- Ruby (https://www.ruby-lang.org/en/) language for simulations.
- Python (https://www.python.org) language for simulations and analysis.
- R (https://www.r-project.org) language for plotting and more.
- Processing (https://processing.org) language for graphics and animations.
- Xcode (https://developer.apple.com/xcode/) for OSX (a somewhat large download)
- MONAD simulator (http://monadsim.herokuapp.com).

9

Interactions Between The Big and The Small

Introduction

It is the interactions between big and small phenomena that mediate much what concerns us.

Game Theory

- *Game theory* is "the study of mathematical models of conflict and cooperation between intelligent rational decision-makers." (https://en.wikipedia.org/wiki/Mathematical_model) [1] (https://en.wikipedia.org/wiki/Mathematical_model)
- Individual actions and reasoning.
- When faced with "commons", individuals make rational decisions.
- "Joker" example' is that how real life works?
- Even if most people cooperate, a few deviating individuals can raid the commons thus depriving the group of such.
- People tend to act in their own self-interests in isolation from the larger benefit of working together.

Tragedy of the Commons

- The *tragedy of the commons* is "where individuals acting independently and rationally according to their own self-interest behave contrary to the best interests of the whole." *Wikipedia* *(https://en.wikipedia.org/wiki/Tragedy_of_the_commons)*, "Tragedy of the Commons".
- & scaling solutions

- (Move elsewhere? Big-Small transition?)
- Related to game theory?
- Small-scale social constraints

Demonstration of Tools

- Ruby is a friendly, easy-to-read programming language that is a useful, easy way to develop simulations. It is a good language for both beginners, brainstorming and rapid prototyping.
- R is both a language and an environment that can used to create plots (graphs) and statistical analysis.
- Processing is a language that is useful for creating simulations as well as running Arduino controllers.

10

Developing a Framework

Introduction

The perspectives and tools previously presented can be used to develop a framework for developing pragmatic sustainability solutions.

A New Framework

Big Sustainability strives to framework a process to develop robust, holistic solutions to sustainability challenges, featuring:

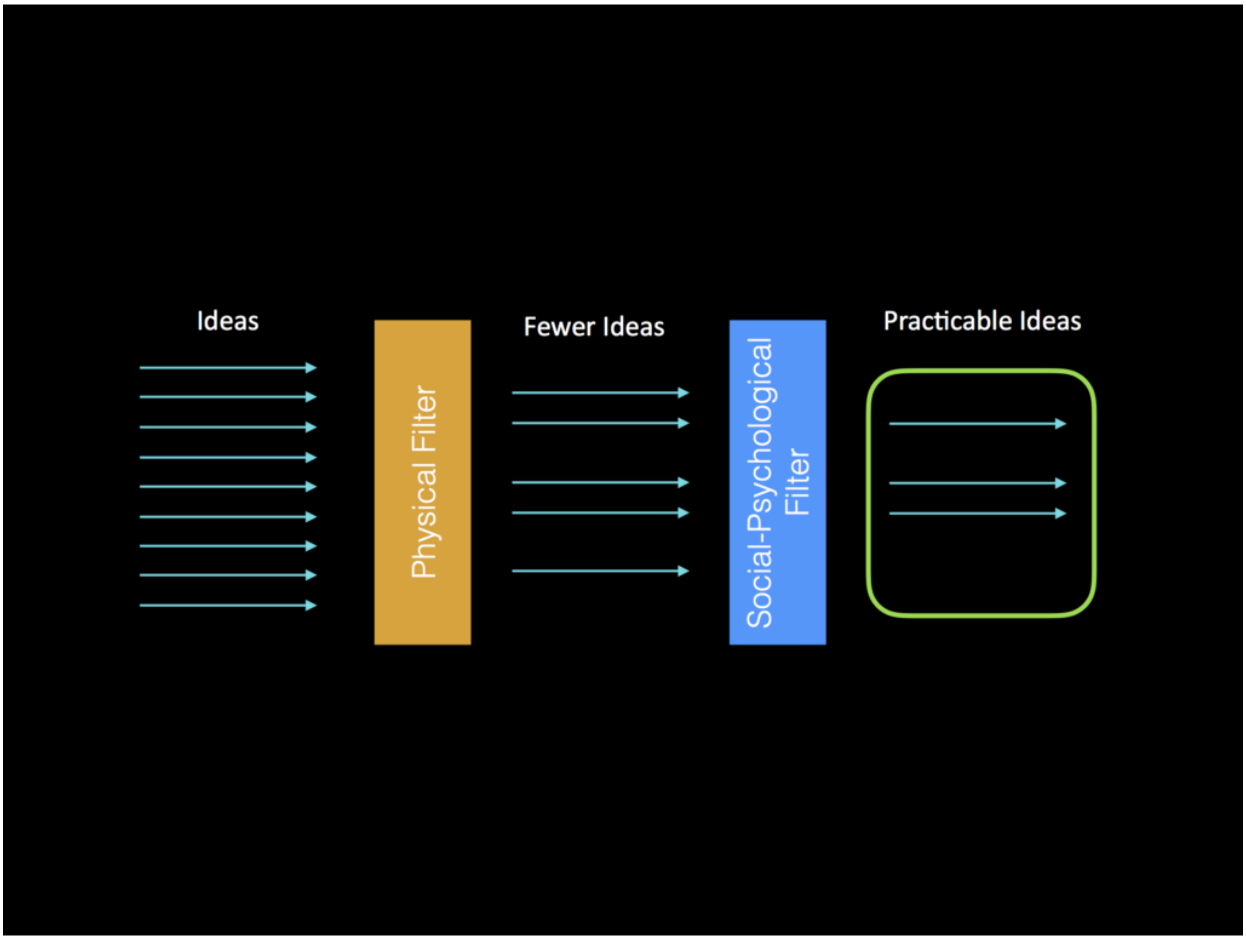
- Account for deep root causes such as build-up of potential, and resulting rise-fall bubble patterns & market oscillations.
- Insist on both physical and social practicality. Brutally and honestly challenge assumptions and listen to the data and people.
- Timed, dynamic solutions that account that take into account changes over time and self-correcting feedback loops.
- Seek "global" optimization while maintaining flexibility to meet individual needs.

Developing Goals, Core Values, Unifying Principles

The first step in the process is to identify your goals, core values, and principles that can be used to unify your group.

Design Principles: Applying the Big and Small Filters

- A solution must be achievable in a physical "big" sense
- A solution must be achievable in a social/psychological "small" sense.



Physical and social filters

Projecting Forward In Time

Many people think of long-term solutions only in the long-term, the final desired end-state. However, people live in the short- and medium-term. What matters between now and the long-run greatly affects our lives.

Hence, it is important to project the progression of the path towards the solution, as well as the progression of the solution past its desired end-state.

Delivering Solutions

1. Research roots of social and physical drivers, and how they translate into human psychology; use the intersection of science, technology and design principles to create a unified science and language of sustainability

1. Develop new tools using system dynamics, cellular automata, new visualization techniques and will create interfaces to new technologies such as big data, AI and new types of data.

1. Create an easy-to-understand and -to-understand use approach to big sustainability

1. Build an interdisciplinary, international and intercultural community of people who are big sustainability-literate and are passionate about making a positive impact for everyone.

1. Solve real problems we are facing everyday regarding environmental, economic and social sustainability.