The Search for Intelligent Life in the Universe
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The Greenhouse Effect

Solar radiation: 343 Watts per m²

Some of the solar radiation is reflected by the atmosphere and the Earth's surface.

Outgoing solar radiation: 103 Watts per m²

Some of the infrared radiation passes through the atmosphere and out into space.

Outgoing infrared radiations: 240 Watts per m²

Solar radiation passes through the atmosphere.

Incoming solar radiation: 240 Watts per m²

About half the solar radiation is absorbed by the Earth's surface.

Absorption solar radiation: 168 Watts per m²

Some of the infrared radiation is absorbed and re-emitted by the greenhouse gas molecules.

Radiation is converted to heat energy, causing the emission of longwave (infrared) radiation back to the atmosphere.
Greenhouse Effect

**Earth's Energy Budget**

- **Incoming solar energy**: 100%
- **Reflected by atmosphere**: 6%
- **Reflected by clouds**: 20%
- **Reflected from earth's surface**: 4%
- **Absorbed by atmosphere**: 16%
- **Absorbed by clouds**: 3%
- **Conduction and rising air**: 7%
- **Absorbed by land and oceans**: 51%
- **Radiated to space from clouds and atmosphere**: 64%
- **Radiated directly to space from earth**: 6%
- **Radiation absorbed by atmosphere**: 15%
- **Carried to clouds and atmosphere by latent heat in water vapor**: 23%

*Image courtesy of NASA.*
Greenhouse Effect

- Moon: daily temperature ($T$) range -175° C (-283° F) to 125° C (257° F)
- Earth: without atmosphere, the global mean $T$ (GMT) is -1° C (30° F)
- Earth: with atmosphere, the GMT is 15° C (59° F)
- Greenhouse gases include H$_2$O (36-70%), CO$_2$ (9-26%), CH$_4$ (4-9%), O$_3$ (3-7%)
- Greenhouse effect on Venus: +250° C

Although H$_2$O dominates, it acts as a positive feedback loop. H$_2$O concentration is directly tied to $T$ through evaporation/condensation. When something else (e.g., CO$_2$) causes a $T$ increase, more H$_2$O evaporates and enhances the $T$ increase.
Global Warming

- Studies of ice core samples have shown there to be a high correlation between temperature and CO$_2$ abundance in the atmosphere, and that CO$_2$ levels are higher now than anytime in last half million years.
Global Warming

- Studies indicate that the rise in CO$_2$ occurs an average of 800-2000 years after the rise in temperature begins.
- Thus, a rise in CO$_2$ does not initially trigger global warming. However, 800 years is very short to typical CO$_2$ cycles (around 100,000 years) so that doesn’t prove CO$_2$ increases don’t also lead to further global warming.
- Climate models show enhanced CO$_2$ leads to higher GMT.
- If rising CO$_2$ was a result of rising GMT, concentrations of CO$_2$ in ocean should be decreasing, contrary to observations. Oceans are also becoming more acidic as they warm.
- Decreasing $^{13}$C, $^{14}$C and O$_2$/N$_2$ proves that extra CO$_2$ in the atmosphere originates from burning buried or stored carbon.
- Models show that global warming results in a larger tropopause and a smaller thermosphere, as observed.
- Rising sea levels and more violent storms predicted: observed.
- Potential exists of releasing CH$_4$ from melting Siberian tundra.
Southern hemisphere CO$_2$ concentration trails northern hemisphere (primary source) concentration by about 5ppm.

84% of additional CO$_2$ is from burning fossil fuels, 10% from deforestation, 5% from cement production and other industries, 1% from volcanic activity.

Life prefers $^{12}$C, so release of fossil C decreases $^{13}$C in atmosphere. Fossil C lacks $^{14}$C, which also decreases in atmosphere. Living plants do contain $^{14}$C, so decrease in $^{14}$C/$^{12}$C cannot be due to brushfires.

The decrease in the O$_2$/N$_2$ ratio parallels the decrease in $^{13}$C since O$_2$ is consumed by burning fossil fuels.

Oceans are becoming more enriched in CO$_2$, but the opposite would occur if they were outgassing it.
Historic CO$_2$, pH and Carbon Isotopic Ratios

Legend
- Mauna Loa atmospheric CO$_2$ (ppmv)
- Aloha seawater pCO$_2$ (latm)
- Aloha seawater pH

Bohm et al. 2002

Tree Rings
[Stuiver and Quay 1981]

Manning & Melhuish 1994

bomb $^{14}$C perturbation

Bomb spike
The carbon cycle is a thermostat, but is not always stable, it can be driven to instability.

Cooling episodes may be connected with removal of methane, a powerful greenhouse gas, from the early Earth atmosphere.

This leads to periods of intense glaciation, called snowball earths, when ice sheets covered virtually the entire planet.

Continuous volcanic activity and decreased erosion increases atmospheric CO$_2$, leading to runaway heating.

Hothouse earths are accompanied by dramatic growths in the magnitude and diversity of life, perhaps leading to the development of eucaryotes and multicellular animals.

Major snowball earth episodes identified:

- 2.2 Gyr ago (Makganyene)
- 710 Myr ago (Sturtian)
- 635 Myr ago (Marinoan), immediately precedes the Cambrian explosion of life.
Evidence for Snowball Earth Episodes

- global glacial deposits
- cap carbonate rocks, indicating anomalous ocean chemistry.

Increased $\text{C}^{13}/\text{C}^{12}$ ratios are consistent with deep freezes that killed off most photosynthetic life in the oceans.

- associated banded iron formations indicating anoxia (depletion of oxygen) in oceans.

Snowball Earth Episodes

![Diagram of Snowball Earth Episodes]

- Global mean surface temperature (°C)
- Paleogeography from Powell et al. (2001)
- Time scale: 10^6 (±) years
- Snowball Earth Episode
- Climate model (Pierrehumbert, 2002)
- Global mean surface temperature (K)

- Regional glaciation
- Global glaciation
- Oxygen level

- Time (billions of years before present)
- Solar System Origin
- Late Heavy Bombardment
- Hadean
- Archean
- Proterozoic
- Phaner"
Preservation of Atmosphere

Atmosphere can be lost

▶ thermal escape
▶ giant impacts
▶ solar wind e.g. Mars

Requirements for planetary magnetic field

▶ abundant Fe
▶ molten interior
▶ convection
▶ rapid rotation
Major Extinctions

Marine Genus Biodiversity: Extinction Intensity

- End P
- End K
- End Tr
- End J
- Late D
- End O
- Middle C
- End S
- Botomani
- Dresbachia

Extinction Intensity (%)

Millions of Years Ago

Percent Extinction per m.y.

Time (m.y.)

James Lattimer
AST 248, Lecture 9
750 Myrs ago, oxygen levels rose from less than 0.1% to 1% of present values (Sturtian).

The snowball earth episode ended with a temporary spike in oxygen, leading to large Edicarian animals by 580 Myrs ago. Life was dominated by cyanobacterial microbial mats. Animals had limited mobility and were not carnivores.

542 Myrs ago, Edicarian animals became extinct and Cambrian explosion ensued.

This seems to be connected with oxygen suddenly crossing, perhaps temporarily, an ecological threshold.

Animals became highly mobile, and evolved legs, compound eyes, gills and jaws. These were clearly carnivorous.

The key seems to have been the emergence of predators.
The Cambrian Explosion

Wikipedia

Hallucigenia (Burgess Shale)

Opabinia

Hallucigenia

Pikaia

Marrella

Aysheaia
Cambrian Explosion

Rate of Molecular Evolution

Rate of Morphological Evolution

Time before Present (millions of years)
Figure 1. Arthropod Lineages during the Cambrian Explosion Are Short in Duration yet Undergo Large Amounts of Phenotypic and Molecular Change Bayesian (BEASTMC3) analysis of 395 phenotypic characters (Supplemental Experimental Procedures SI_2) and 62 nuclear genes (Supplemental Experimental Procedures SI_3). Branches and taxa in these three trees are in identical order and have the same color coding. Note the large amount of change indicated by the long bold branches in (B) and (C), and the corresponding short durations of these branches in (A). For details of specimen illustrations, see Supplemental Experimental Procedures SI_14.
What is the Definition of Life

Organization or Order  Cell structures formed from specific molecular patterns.

Homeostasis  Regulates its internal environment to maintain a stable, constant condition.

Growth and Development  Directed by heredity. Organism increases in size of its parts, doesn’t just accumulate mass.

Reproduction  Cells divide both to make new organisms and new cells for growth. Some can’t reproduce – mules. Others, like viruses and prions, don’t reproduce by themselves.

Metabolism or Energy Utilization  To create and maintain patterns of order, to reproduce, and to grow. Energy used to counter increasing disorder mandated by 2nd law of thermodynamics.

Response to Environment or Stimuli  Capable of responding to environmental changes or stimuli (touch, light, sound), involving active responses such as motion. All necessary but not sufficient

Evolutionary Adaptation  Permanent changes carried by heredity to evolutionary pressures, resulting in positive adaptations and entirely new species. Sufficient
Evolution of Evolution

- Anaximander (Greek, 610-547 BC) – simple life originally arose in water and gradually evolved to more complex forms.

- Empedocles (492-432 BC) – suggested creatures poorly adapted to their environment would perish, foreshadowing adaptation.

- Aristotle – maintained that species are fixed and non-evolving. Eventually became view adopted by the Church and fundamentalists.

- Jean Lamarck (1809) – fossils represent extinct ancestors of living species.
  - Organisms possess a built-in drive for perfection
  - Organisms can adapt to circumstances
  - Simple organisms spontaneously created, evolve to greater complexity
  - Organisms inherit characteristics acquired by ancestors
Evolution of Evolution, continued

- Charles Darwin and Alfred Wallace (1850) – Supplied evidence for evolutionary changes and put forth a model of how evolution occurs (natural selection).
  - Populations have the potential to overreproduce, leading to scarcity of resources, and competition for survival.
  - Individuals within a population vary in many heritable traits, some of which make them more competitive.
  - These lead inescapably to unequal reproductive success among individuals, the population ultimately becoming progressively populated by the more competitive individuals.
- The biological environment is not static but evolving.
- Similar organisms are related, descend from a common ancestor; all life forms are descendant from a single common ancestor. Darwin tree
- Evolutionary change is the result of natural selection.
- Evolution is gradual and continuous. Here Darwin was heavily influenced by Charles Lyell’s *Principles of Geology*. 
Evidence for Darwinian evolution

- Galapagos Island finches
- giant armadillo fossils in Brazil
- selective breeding: mustard into broccoli, cauliflower, cabbage, brussels sprouts, kale and kohlrabi; dogs

On the Origin of Species – Darwin
Modern Synthesis with Genetics

- Evolution is the cornerstone of modern biology, and is a fact – defined as “confirmed to such a degree that it would be perverse to withhold provisional consent” – not a theory.
- In evolution, the whole population, not individuals, is what counts. Evolution is a change in the gene pool of individuals over time.
- Variations in individuals are caused by genetic differences.
- Populations are collections of individuals which evolve.
- A single organism is never typical of an entire population; individuals do not evolve – populations evolve.
- Genes can change between generations because of sexual reproduction and mutations.
- When mutations first occur, they are not adaptive because most mutations are detrimental. The short-term effect of mutations is minimal or nil.
- Longer-term, the accumulation of mutations and random shuffling of genes through reproduction or migration from another population provides the source of variation in a population.
- Natural selection controls the direction, rate and intensity of evolution.
- Sudden, catastrophic environmental changes can force a speed-up of evolution.
- The only scientific controversy surrounding evolution is exactly how it occurs, not if it occurs.
Evidence for Evolution

Fossil Record – Paleontology  Fossil record provides consistent evidence of systematic change through time—of descent with modification. It can be predicted that no reversals will be found in future paleontological studies.

Common Structures – Comparative Anatomy  Scientists call strikingly similar structures in varied species homologies and have concluded that they are best explained by common descent.

Distribution of Species – Biogeography  Simultaneous wide diversity and specialization. Geographical isolation (Hawaii, Australia, Galapagos)

Similarities During Development – Embryology  Ontogeny recapitulates phylogeny: Although discredited in detail, if a structure pre-dates another structure in evolutionary terms, then it also appears earlier in the embryo. Related species typically share the early stages of embryonal development and differ in later stages. A wide variety of organisms from fruit flies to worms to mice to humans have very similar sequences of genes that are active early in development. The cerebrum in humans, the most sophisticated part of the brain, develops last.
Molecular Evidence – The Unity of Life

The code used to translate nucleotide sequences into amino acid sequences is essentially the same in all organisms. The same amino acids and proteins are universally used.

Metabolism is universally carried out by the ATP-ADP cycle.

Hemoglobin and myoglobin, among others, sequencing shows family trees identical to those derived from paleontology and anatomy. Genetic sequencing and molecular clocks reinforce this.

Pseudogenes, which are remnants of genes that no longer function but continue to be carried along in DNA as excess baggage (junk DNA). Pseudogenes change through time, as they are passed on from ancestors to descendants, reconfirming other observations.
Catastrophism vs. Uniformitarianism

- Georges Cuvier argued for catastrophism on the basis of geological evidence (canyons in southern France).
- Charles Lyell debated in favor of gradualism, partly because of the negative religious fundamentalist connotations of catastrophism (e.g., biblical flood). Lyell was trained as a lawyer, and won debate.
- Darwin was heavily influenced by Lyell and his own observations of gradual changes in finches, etc.
- Fossil record in early 19th century was very limited; the missing pieces were thought to be due to incomplete sampling rather than being evidence for rapid changes connected with extinctions. Now that the fossil record is much more complete, evidence for catastrophes is more obvious.
- Abundant evidence has accumulated to indicate that evolution proceeds in spurts and starts rather than gradually – the Punctuated Equilibrium Theory of Eldridge and Gould posits that the dominant evolutionary changes, involving both extinctions and originations, occurred during very short violent catastrophic events.
  - Mass extinctions at boundaries between geologic eras: Permian 250 Myr BC, Cretaceous/Tertiary 65 Myr BC.
  - Sudden originations of several families of animal types during the Cambrian explosion 540 Myr BC
  - Thought to be caused by impacts, supernovae, plate tectonics, development of Earth’s magnetic field, oxygenation of atmosphere.
Principal Creationist Objections

Evolution is just a theory. Scientist’s use of theory is different than general public. Gravity is a theory, but is essentially a fact from observations.

There are no fossil intermediates – missing links. Darwin worried about gaps in the fossil record. Since then most fossil intermediates in vertebrate evolution have been found. Invertebrate fossils are much rarer; gaps are expected.

Intelligent design – life is too complex. The intermediates in the evolution of the ear and eye are observed. Complex structures evolved as a progression of slight improvements.

Evolution violates 2nd law of thermodynamics. The 2nd law really says: disorder increases in a closed system; the Earth is not. Solar energy is received and the Earth reradiates it.

Proteins are too improbable. Hemoglobin has 140 amino acids. Probability that first one would be leucine is 1/20, and that all 140 would be the ones they are by chance is \((1/20)^{140} = 7.2 \times 10^{-183}\), an impossibly rare event.

Statistical foolishness: You cannot use probability to argue backwards. The probability that everyone in a class of 50 would have the birthdays they do is \((1/365)^{50} = 7.6 \times 10^{-129}\).
Natural selection does not imply evolution. Microevolution (evolution within a species) seems to be the mechanism that has produced macroevolution (evolution among species). Man-made selections alone are remarkably distinctive: dachshunds, chihuahuas and greyhounds; mustard and cauliflowers.

Irreducible complexity. If each part of a complex process like blood clotting is essential, how can natural selection fashion any one part? What’s wrong with this argument is that each part of a complex molecular machine evolves in tandem as part of the system. Blood clotting evolved from a much simpler system which originated 600 Myrs ago in lampreys, the most primitive fish. Proteins were incorporated 100 Myrs later in the first vertebrates. 50 Myrs later clotting triggered by contact with jagged surfaces evolved. Mammalian clotting now relies on all three components and can’t act independently of any of them.
Belief in Evolution Versus National Wealth

The black line is the equation

\[ y = A(1 - B/x) \]

which fits best for

A = 101 and B = 9260

(U.S. excluded from fit)

†-Percent of adults that answered "true" to the question "Human beings, as we know them, developed from earlier species of animals."
From Jon Miller et al., Science, Aug 2006

* - GDP adjusted for purchasing power parity (PPP). Data from the CIA World Factbook
Growing Partisan Differences in Beliefs About Evolution

% of U.S. adults in each group saying that humans and other living things have existed in their present form since the beginning of time, or humans and other living things have evolved over time

- Evolved over time
- Existed in present form since beginning

### Republicans

<table>
<thead>
<tr>
<th>Year</th>
<th>Evolved over time</th>
<th>Existed in present form since beginning</th>
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<tbody>
<tr>
<td>2013</td>
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<td>48</td>
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<td>2009</td>
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### Democrats

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### Independents

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<td>28</td>
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<tr>
<td>2009</td>
<td>67</td>
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Source: Pew Research Centers survey March 21-April 8, 2013. Q54, Q56. Those saying “don’t know” are not shown.

PEW RESEARCH CENTER
Political groups are worlds apart in their beliefs about climate change

% of U.S. adults in each group who say climate change is mostly due to human activity/mostly due to natural patterns/there is no solid evidence that Earth is getting warmer

<table>
<thead>
<tr>
<th></th>
<th>Because of human activity</th>
<th>Because of natural patterns</th>
<th>There is no solid evidence</th>
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<td>Mod/lib Republican</td>
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<td>46</td>
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<tr>
<td>Mod/cons Democrat</td>
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<tr>
<td>Liberal Democrat</td>
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Note: Beliefs about climate change include those who “lean” toward each response. Republicans and Democrats include independents and other non-partisans who “lean” toward the parties. Respondents who do not lean toward a political party and those who did not give an answer are not shown.


PEW RESEARCH CENTER

A decade of political divides over climate change

% of U.S. adults in each group who say the Earth is getting warmer mostly because of human activity

Trend based on two questions, 2006-2015

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<th>Republican</th>
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Note: Republicans and Democrats include independents and other non-partisans who “lean” toward the parties. Respondents who do not lean toward a political party, those saying “don’t know,” and other responses are not shown.


PEW RESEARCH CENTER
Scientific agreement on human-caused global warming

- Scientific Consensus (%)
- Expertise in climate science

- Africa
- Asia/Pacific
- Europe
- Russia/Ukraine
- Latin America
- Middle East
- North America

CO₂ Emissions per Capita in Metric Tons (2011)

United States