Evolution
Darwinian Definition of Life

• Self-sustaining and reproducing

• Capable of evolving
Origin of Life

The problem: to go from

- Simple inorganic molecules
  - $\text{H}_2\text{O}$, $\text{NH}_3$, $\text{CH}_4$, FeS
- And energy
  - Lightning, UV radiation, heat
- To simple organic molecules
  - Amino acids, nucleotides
Miller-Urey Experiment

\[ \text{CH}_4 + \text{NH}_3 + \text{H}_2\text{O} + \text{electric spark} \Rightarrow \]

simple amino acids

Variants with different ingredients and energy sources also yield organic compounds
From Chemistry to Life

- Clays facilitate self-assembly of larger molecules
- Eventually, a self-replicating molecule will arise
- Lipids form coacervates, trapping organic molecules
- RNA arises
  (5 bases $\Rightarrow$ enzyme; 165 bases $\Rightarrow$ self-replication)
Darwinian Evolution

Evolution is reproduction with error.

Error means changes in the DNA base sequence

Many changes are neutral, because
• codons are redundant
• many mutations happen in junk DNA
The Molecular Basis of Evolution

DNA Base pairs encode amino acids (e.g., TAC encodes Tyrosine). Genes encode proteins (strings of amino acids).

- Some proteins are structural - they make parts of things
- Some proteins are controls - they control gene expression

Mutations result from:
- incorporation of new genes (viruses and bacteria readily share genetic material)
- substitutions of bases (TAC → TTC replaces tyr with phe)
- breaks in genes (TAC → TAA replaces tyrosine with stop)
The Molecular Basis of Evolution. II

- Most mutations are deleterious.
- Some mutations are neutral.
- A few mutations are beneficial.
- Mutations in structural genes have small effects.
- Mutations in control genes have major effects.
- Mutations are random, but
  - since deleterious changes kill,
  - advantageous and neutral mutations accumulate.

That which does not kill me makes me stronger
The Cause of Mutations

Genetic damage due to radiation
- Photons (X-rays, $\gamma$-rays)
- Particles (cosmic rays)

Transcription errors
Particulate Radiation

Alpha particles
- Helium nuclei
- penetrate < 10 cm in air, 60 µm in tissue
- stopped by paper

Beta particles
- Electrons
- Penetrate a few mm into tissue

Neutrons

Fission Fragments
Electro-Magnetic Radiation

Penetrating radiation:
• X-rays
• γ rays
How Radiation Causes Mutations

- Atomic bonds require about 10 electron volts energy (about $10^{-11}$ erg) to break
- EM Radiation energy = $hc/\lambda$
- $\lambda < 120$ nm corresponds to $E > 10$ eV
  - solar UV-b [$\lambda < 300$nm] can damage DNA
  - solar UV-a [$\lambda < 400$nm] damages collagen
Definitions

1 Becquerel (Bq) = 1 disintegration/second (dps)
1 Curie = $3.7 \times 10^{10}$ dps
1 Röntgen = amount of ionizing radiation that produces 1 esu/cm$^3$ in dry air
1 rad (Röntgen absorbed dose) = 100 erg/gm
1 Gray (Gy) = 100 rads = 1 Joule/kg
Dose = $0.869 f$ rad
   $f$ = mass absorption coefficient/air
Rem (biological equivalent dose) = rads x QF
   QF (quality factor) $\approx$ # ion pairs / cm
1 Sievert (Sv) = 100 rem
Radioactivity Levels

- Human being: 3000 Bq
- Kg of coffee: 1000 Bq
- Kg of Granite: 1000 Bq
- Kg of coal ash: 2000 Bq
- Air inside a 100 m^2 house: 3000 Bq
- Kg, superphosphate fertilizer: 5000 Bq
- Smoke detector: 30,000 Bq
- Kg of low level radioactive waste: 10^6 Bq
- Kg of Uranium: 10^7 Bq
- Medical radioisotopes (diagnosis): 10^9 Bq
- Medical radioisotopes (therapy): 10^14 Bq
Can You Avoid Radiation?

No.

<table>
<thead>
<tr>
<th>Source</th>
<th>Dose Rate (millirem/year)</th>
<th>Lifetime Cancer Risk assuming validity of LNT*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indoor radon</td>
<td>200</td>
<td>7,500 per 1,000,000</td>
</tr>
<tr>
<td>Cosmic rays (at sea level)</td>
<td>30</td>
<td>1,100 per 1,000,000</td>
</tr>
<tr>
<td>Cosmic rays (Denver at 5000 ft elevation)</td>
<td>55</td>
<td>2,000 per 1,000,000</td>
</tr>
<tr>
<td>Human body (from food we eat)</td>
<td>40</td>
<td>1,500 per 1,000,000</td>
</tr>
<tr>
<td>Soil and rock</td>
<td>30 - 50</td>
<td>1,100 to 1,900 per 1,000,000</td>
</tr>
<tr>
<td>Soil and rock (Colorado plateau)</td>
<td>90</td>
<td>3,400 per 1,000,000</td>
</tr>
<tr>
<td>Living in a brick house</td>
<td>7</td>
<td>260 per 1,000,000</td>
</tr>
<tr>
<td>Working in granite buildings</td>
<td>50 - 200</td>
<td>1,200 per 1,000,000</td>
</tr>
<tr>
<td>One round trip from LA to NY</td>
<td>6</td>
<td>3 per 1,000,000</td>
</tr>
<tr>
<td>Smoking 1 pack of cigarettes per day (polonium-210)</td>
<td>8,000</td>
<td>200,000 per 1,000,000</td>
</tr>
<tr>
<td>Sleeping next to one’s partner</td>
<td>2</td>
<td>50 per 1,000,000</td>
</tr>
</tbody>
</table>

*LNT. The linear-no-threshold (LNT) model of radiation risk assumes even the smallest incremental exposure to radiation has an associated cancer risk. There is no scientific evidence to support this theoretical model.*
Evolution of Microbes

Mutations are important, since they will be copied (transcribed) into future generations.

Microbes may have a new generation every 30 minutes.

Microbes also share genetic material.
Genetic Diversity

A population carries lots of diverse traits.
• Some are crucial,
• Some are beneficial,
• Some are detrimental,
• Some are neutral

If the environment does not change
• The population of beneficial traits increases
• The population of detrimental traits decreases

Traits are ultimately determined by genes
Natural Selection

Black dots represent deleterious mutations

Evolution results from the accumulation of advantageous mutations
Diversity and Stress

If the environment changes, the population may be stressed

- *Beneficial traits* may no longer be beneficial
- *Detrimental traits* may become useful
- *Neutral traits* may become beneficial or detrimental

The population will change in response to *stress*
Mutations in the Higher organisms

Single-point mutations, except in germ cells, are unimportant.

Isolated populations change in response to different environmental stresses.

Over time, isolated populations may change sufficiently that they can no longer inter-breed. This is the definition of distinct species.
How Evolution Really Works

Mutations accumulate at a more-or-less constant rate. **Darwinian** evolution is **Uniformitarian**: changes are slow and almost imperceptible. The Darwinian model is refuted by the data. **Most evolutionary change seems to be rapid.**

**Catastrophism** or **Punctuated equilibrium**:
- Pool of variants (or mutants) exist in populations
- Variants may be advantageous when conditions change, as they may be better adapted to the new conditions
- Monocultures can be ill-adapted to change
- Evolutionary change occurs in short bursts when environments change
How Evolution Really Works

New **phyla** do not appear gradually throughout the fossil record: they appear almost all at once in the *Cambrian Explosion*, 530 Mya.

- Well-adapted *species* need not change
  (e.g., cyanobacteria, thermophilic bacteria)
- *Eukaryotes* evolved in response to the first major global environmental disasters:
  - Oxygen and the first ``snowball Earth"
- *Animal life* appeared in the Cambrian Explosion, perhaps in response to the second “snowball Earth"
- New species appear, and new classes arise to dominance, following global disasters (catastrophism).
The Direction of Evolution

There is none. Evolution is blind.

All living species are successful.

All living species are adapted to their environment.

Some have failed to adapt to change, and become extinct.

The average species survives about 1 million years.
It’s a Long Way from Amphioxus
Proof of Evolution

• Genetic control sequences (*homeobox genes*) are common in all terrestrial life.

• Humans and bacteria have genes and proteins in common.

• The TATA gene, which encodes the protein that activates genes, is 40% identical between humans and bacteria.

• The human and chimpanzee genomes are about 98% identical.
Is Evolution only a Theory?

Yes. But so is gravity. It is a fact that evolution happens.

• *Microevolution* is observed - e.g., drug resistance in bacteria.
• *Macroevolution* is observed in the fossil record
Is Evolution only a Theory?

• There is also a *theory of evolution* which explains the facts. Some details of the theory are incompletely understood.
  
  • *Darwinian evolution* may be an incorrect theory;
  • *Punctuated Equilibrium* may be better.

• Evolutionary theory makes clear predictions, many of which have been borne out
• Many criticisms of evolution reflect a misunderstanding of science and how it operates
• The strength of science is that theories change in response to better knowledge
• Most criticisms of evolution are philosophical, not scientific
What About Intelligent Design?

*Well-adapted* is not synonymous with *well-designed*.

- The eye has evolved >65 times, with 10 different designs.
  - The mammalian eye evolved from brain tissue.
  - The molluscan eye evolved from skin tissue.
  - The molluscan eye has a superior optical design. In mammalian eyes the light must pass through the nerves and blood vessels before reaching the retina. We have a large blind spot where the optic nerve is located. It takes a large brain, and lots of processing, to make the undistorted images we perceive.

- The genome is redundant (inefficient design)
  - $\beta$ globin, a protein used in hemoglobin, is encoded 6 times in humans. Adults use two versions of the protein; children use 3
  - one version contains 6 known errors, and is non-functional.
What About Intelligent Design?

~97% of our DNA is not expressed (inefficient design). It is gene fragments, pseudogenes, or repeated nonsense segments. (but some pseudogenes seem to play regulatory roles)

Upon close examination, our DNA is a hodgepodge of "borrowed, copied, mutated, and discarded sequences, cobbled together by millions of years of trial and error." (S.J. Gould)

Further Reading:
Another good essay, with lots of references, is at http://skeptics.com/intelligentdesign.html (from the Skeptic's Dictionary)
A recent article discussing the inroads intelligent design is making in academia is located at http://chronicle.com/free/v48/i17/17a0001.htm (from the Chronicle of Higher Education)