Overview of Chapter 2

- Ancient Debate about Life Beyond Earth (2.1)
  - Greeks and Geocentrism
- The Copernican Revolution (2.2)
  - Copernicus, Tycho, Kepler, Galileo, Newton
- The Nature of Modern Science (2.3)
  - The scientific method

But First – Writing Science Answers

- Regarding answering science questions
  - Complete sentences
  - Science reasoning
  - Specific examples
  - Numbers/formulas once in a while is nice
  - Use all information given
  - Answer can start with words from question

Example Question

Evaluate the given statement and decide whether it makes sense. Explain your reasoning clearly.

Even if we discover a civilization around other stars, we will never be able to talk with them with the same ease with which we carry on conversations with people on Earth.

Sample Answer

Given that we discover a civilization around other stars, let's examine the closest that such a civilization could be from the Earth. The nearest star is 4.3 light years distant from Earth. This means that a two-way conversation would take at least 8.6 years, since no information can travel faster than the speed of light. While this is well within a human lifetime of say 75 years, it is a long time for a conversation. There would be a delay of at least 8.6 years for any two-way conversation between any civilization ever discovered. This does not represent an ease with which we carry on conversations with people on Earth. The maximum distance between any two points on Earth is about 26,000 miles (the approximate circumference of the Earth), much less than the speed of light travels, which is approximately 186,000 miles per second. Therefore, the given statement makes sense.
Another Sample Question

Evaluate the given statement and decide whether it makes sense. Explain your reasoning clearly.
* If the universe did not contain stars more massive than our Sun, we couldn’t be here.

Sample Answer Related to Chapter 1

The chemical elements upon which all life on Earth is based upon, includes many elements heavier than lithium, such as carbon, nitrogen, and oxygen. All elements heavier than lithium were produced in stars that died as supernovae, long before our Sun was formed. A star like our Sun, can only form elements up to carbon. Elements beyond carbon require stars that are greater than about 3.8 solar masses. Therefore, **the statement given makes sense** since we need heavier stars to make the chemical elements upon which our lives are based. In fact, only the most massive stars, greater than about 10 solar masses, will ever form the chemical elements of iron and those more massive than iron, up to and including uranium.

Now, back to Chapter 2...

Universality of Chemistry and Physics?

* Are laws of physics universal?
  - What do we mean by universal?
  - What do we mean by Laws of Physics?
  - How do we know they operate in the universe?

* Are laws of chemistry universal?
  - What do we mean by universal?
  - What do we mean by Laws of chemistry?
  - How do we know they operate in the universe?

Universality of Biology?

* Characteristics (laws?) of biological systems universal?
  - What do we mean by universal?
  - What do we mean by characteristics of biological systems?
  - How do we know they operate in the universe?

Universality of Biology?

* Reasons for optimism
  - Early Earth’s innate constituents formed complex carbon-based organic molecules (e.g., carbohydrates, lipids, nucleic acids, etc.)
  - Observation of comparable organics on meteorites
  - Step from chemistry to biology not difficult (thermodynamically)
  - Life arose very early on Earth (first 10% of time)
  - Conditions on Earth were right even though extreme
  - Success of “extremophiles”
  - High probability that principle characteristics of life are universal

Science of Astrobiology (by any other name)

* Exobiology
* Bioastronomy
* Astrobiology
  - NASA (National Aeronautical and Space Administration)
  - Study of life in the Universe
* Generally accepted components (remember ODDS)
  - Beginnings of life on Earth and its evolution
  - Life elsewhere in the Universe
  - Future of life on Earth and elsewhere
The Beginnings of Astrobiology

- **Mythology (< 600 BC)**
- **Thales and Pythagorus (~600 BC - 500 BC)**
  - Geocentric view of earth and solar system
  - Composition of nature: water, fire, earth and air
- **Atomists (~600 BC - 400 BC)**
  - Universe composed as noted above
  - Multiple worlds with life
- **Key ideas of Atomist**
  - Random events elsewhere as on Earth
  - Geocentric view
  - Atom-like chemistry
  - Really not science – more intuition and philosophy

Historical Debate on Life in Other Worlds: Speculation

- **Mythology (< 600 BC)**
- **Atomists (~600 BC - 400 BC)**
- **Aristotelians (~400 BC - 300 BC)**
- **Christianity (Middle Ages)**
- **Transition: Speculation to Science**
- **Copernican Revolution**
- **Revolution in the Life Sciences and Geology**
- **Summary: role of science versus speculation**

Speculation Continued

- **Aristotelians (~400 BC - 300 BC)**
  - Plato (400 BC) and Aristotle (350 BC)
  - Rejected atomists
  - Tenets: 4 elements plus “aether”
  - Geocentricism
  - Uniqueness of the Earth
  - Integration into Christianity in 1250 AD by St. Thomas Aquinas

Speculation Continued

- **Pluralism and Christianity (Middle Ages)**
  - Plurality of worlds: many worlds in the Universe
    - Christian scholars: problem
    - Jewish scholars: no problem
    - Islamic scholars: no problem
    - Eastern Religions scholars: no firm position
- **From Speculation to Science**
  - Key to all of the above: speculation not science
  - Why?
  - What events trigger the transition from speculation to science (1450?)

The Road to the Copernican Revolution

- **Key:** “models” of how nature operates
  - Define model: conceptual, mechanistic, mathematical
  - Outline approach: observation followed by construct
  - Models fail (and this is good!!)
- **Ptolemy Model of the Solar System (1150 AD)**
  - Geocentric, “circle-upon-circle”, tricks, all paths circular
  - Reasonable accuracy of model

iClicker Question

- **In the Greek geocentric model, the retrograde motion of a planet occurs when**
  - **A** Earth is about to pass the planet in its orbit around the Sun.
  - **B** the planet actually goes backward in its orbit around Earth.
  - **C** the planet is aligned with the Moon in our sky.
Copernicus

- Copernican Model: planetary motion explained by Sun-centered solar system
  - Circular orbits and "circle-upon-circles"
  - Reasonably accurate
- Tycho Brahe
  - Quality data via naked-eye observations for 3 decades
  - No model

iClicker Question

Which of the following was not a major advantage of Copernicus’ Sun-centered model over the Ptolemaic model?
- A It made significantly better predictions of planetary positions in our sky.
- B It offered a more natural explanation for the apparent retrograde motion of planets in our sky.
- C It allowed calculation of the orbital periods and distances of the planets.

iClicker Question

How did the Copernican revolution alter perceptions of the ancient Greek debate over extraterrestrial life?
- A It showed that Aristotle’s argument for a unique Earth was incorrect.
- B It showed that the atomists were correct in their belief in an infinite cosmos.
- C It proved that extraterrestrial life must really exist.

Kepler’s Laws of Planetary Motion

- Kepler’s First Law of Planetary Motion
  - Planets orbit sun in an ellipse with sun at one focus
- Kepler’s Second Law of Planetary Motion
  - Planets sweep out equal areas in equal times, travel faster when closer, slower when farther away
- Kepler’s Third Law of Planetary Motion
  - Orbital period squared is proportional to semi-major axis cubed
    - \( P^2 = a^3 \)

iClicker Question

Earth is closer to the Sun in January than in July. Therefore, in accord with Kepler’s second law
- A Earth travels faster in its orbit around the Sun in July than in January.
- B Earth travels faster in its orbit around the Sun in January than in July.
- C Earth travels at the same rate in its orbit around the Sun in January and July.

iClicker Question

According to Kepler’s third law
- A Mercury travels fastest in the part of its orbit in which it is closest to the Sun.
- B Jupiter orbits the Sun at a faster speed than Saturn.
- C All the planets have nearly circular orbits.
Tycho Brahe’s contribution to astronomy included
- A inventing the telescope.
- B proving that Earth orbits the Sun.
- C collecting data that enabled Kepler to discover the laws of planetary motion.

Galileo’s contribution to astronomy included
- A discovering the laws of planetary motion.
- B discovering the laws of gravity.
- C making observations and conducting experiments that dispelled scientific objections to the Sun-centered model.

Newton’s Laws of Motion and Gravity

Newton’s First Law of Motion
- A body at rest tends to stay at rest and a body in uniform motion will stay in straight line uniform motion unless acted upon by an outside force

Newton’s Second Law of Motion
- The acceleration of a body is proportional to the force being applied
  \[ F = m a \]

Newton’s Third Law of Motion
- For every force there is an equal and opposite force (action and reaction)

Newton’s Law of Gravitational Attraction
- The force is proportional to masses and inversely proportional to the distance squared
  \[ F = \frac{G m M}{r^2} \]

The general theory of relativity is our most accurate description of gravitation
- Published by Einstein in 1915, this is a theory of gravity
- A massive object causes space to curve and time to slow down
- These effects manifest themselves as a gravitational force
- These distortions of space and time are most noticeable in the vicinity of large masses or compact objects
The theory of relativity predicts a number of phenomena, including the bending of light by gravity and the gravitational redshift, whose existence has been confirmed by observation and experiment.

The representation of gravity as a curvature of space similar to a flexible rubber sheet was first expressed in Einstein’s Special Theory of Relativity.

The Principle of Equivalence explains which of the following concepts?

A. Weight and mass are the same thing.
B. Equal masses have equal forces of gravity causing everything to fall at equal speeds.
C. The force of gravity equals the force of matter.
D. The force of gravity is equal on all masses.
E. The force of gravity is greater on bodies with a greater mass causing all masses to fall to Earth with the same acceleration.

The general theory of relativity also predicts the existence of gravitational waves, which are ripples in the overall geometry of space and time produced by moving masses. Gravitational waves have been detected indirectly, and specialized antennas are under construction to make direct measurement of the gravitational waves from cosmic cataclysms.

The general theory of relativity predicts black holes.
If a stellar corpse has a mass greater than about 2 to 3 $M_{\odot}$, gravitational compression will overwhelm any and all forms of internal pressure. The stellar corpse will collapse to such a high density that its escape speed exceeds the speed of light.

Suppose you were watching an unfortunate fellow astronaut falling into a black hole. Compared to your ship’s master clock, the watch on her wrist, as you see it (and while you still can see it), would be running

A. backwards
B. faster
C. slower
D. at the same rate
E. none of the above is true

Certain binary star systems probably contain black holes:

- Black holes have been detected using indirect methods.
- Some binary star systems contain a black hole.
- In such a system, gases captured from the companion star by the black hole emit detectable X rays.
Supermassive black holes exist at the centers of most galaxies. These are detected by observing the motions of material around the black hole.

String Theory: the idea

- All matter consists of small one-dimensional objects (strings).
- Strings look like particles when not resolved closely enough.
- All particle types are different normal modes of the string.
String Theory: the interactions

- All interactions consist of the splitting and joining of these elementary strings.
- This is the only known sensible description of the scattering of gravitational waves at very high energies.
- Looks like General Relativity plus other interactions at low energies.
- No parameters: string length sets units.

Possible Downsides

- At first sight there appeared to be a number of different kinds of string theories.
  - Open, closed, heterotic, Type I, Type IIA,...
- Predicts we live in 10 spacetime dimensions!
  - Experimental update: number of (large) dimensions = 4
- Very difficult to experimentally test so far.
  - Strings are so short that once the symmetries and spectrum are gotten right, most of the details are usually also right.
  - Calculation gets known masses right, but....
    - experiment $m_{\text{exp}} = 0.00000000$,...
    - theory $m_{\text{th}} = 0.0000000$

D-Branes

- String theory is bigger than previously thought.
  - String ends move at light speed.
  - String ends live on a surface.
  - This surface is interpreted as a large massive object, a D-brane, in spacetime.

Why Do This?

- Good Things Happen if the theory has both strings and D-branes:
  - Previously-hidden duality symmetries emerge, with all known string theories dual to one another under these symmetries!
  - Some weakly-interacting string theories are the duals of the strong-coupling limit of others!
  - Led to discoveries of similar symmetries amongst ordinary particle theories.
- Conjecture: all known string theories are different solutions to a more fundamental (11-dimensional) theory (M Theory).

Brane vs Bulk States

- Important Brane Facts:
  - At low energies some states are trapped to live near the Brane
    - eg: Open strings terminating on a Brane.
  - Other states - Bulk states - can ramble:
    - eg: Closed strings, including gravitons.
  - Trapping is not really so weird.
  - Similar to the trapping of ‘zero modes’ on defects like vortices and domain walls in solids.
- Brane-World Scenario: All known particles are so trapped.

Revolution in the Geological Sciences

- Historical concept of a static Earth (crustal antiquity)
- Wegener (1920): Theory of Continental Drift
- Hess (1960): Theory of Plate Tectonics
- Emergence of climatology as a science (1960’s)
- Past (palaeoclimatology) to current to future
- Dynamic Earth and affect on living organisms
Rise of the Life Sciences

- Darwin’s Theory of Evolution (1859)
  - Struggle for survival, natural selection and origin of species
- Mendel’s Theory of Particulate Inheritance (1860)
  - Traits are inherited from generation to generation
- Watson and Crick (1950’s): Discovery of DNA
  - Molecular explanation for Mendel’s theory (looking back)
  - Catapulted life sciences into new dimension and prominence (forward looking)
- Metabolism and molecular biology (1970-2002+)
  - Gene regulation affects the chemistry of cells
- Genetic engineering and bioinformatics: new frontier (2000 and beyond)

Revolution in the Sciences and Question of Life in Universe

- The process of change (speculation to science)
- Change in human perspective (stars are just not lights but other worlds)
- Idea of extraterrestrial life
- Universality of Laws of physics
- Universality of Laws of chemistry
- Dynamic state of Earth’s geology
- Rise of the life sciences (from Darwin to bioinformatics)
- Universality of characteristics of living systems (?)

Hallmarks of Science

- Driven by observations
- Foundation in logic
- No special circumstances
  - No miracles in science
- Occam’s razor (KISS principle)
- Falsifiability
  - Things not testable are not scientific

The Scientific Method

- Observations
- Hypothesize
- Test hypothesis
  - What does hypothesis predict beyond current observations?
  - Maxwell’s demon
- More observations

Nonscience and Pseudoscience

- UFOs
- Astrology
- Psychics/Mediums
- Big foot
- Levitation
- Telepathy
- Crop circles
- Gemstone cures
- Uri Geller
- Tarot cards
- Nessie
- Fortune telling
- Nostradamus
- Channeling
- Magnetic cures
- Telekinesis

iClicker Question

- Which of the following is not true about scientific progress?
  - A Science progresses through the creation and testing of models of nature.
  - B Science advances only through strict application of the scientific method.
  - C Science avoids explanations that invoke the supernatural.
iClicker Question

Which of the following is not true about a scientific theory?
- A  A theory must explain a wide range of observations or experiments.
- B  Even the strongest theories can never be proved true beyond all doubt.
- C  A theory is essentially an educated guess.

Some Science References

- Committee for the Scientific Investigation of the Paranormal
  - http://www.csicop.org/
  - The Skeptical Inquirer

- The Skeptics Society
  - http://www.skeptic.com/
  - Skeptics magazine

- Books
  - Demon Haunted World (Sagan)
  - Why People Believe Weird Things (Shermer)
  - Flim Flam (Randi)
  - Fads and Fallacies in the Name of Science (Gardner)

Summary

- Geocentrism, Heliocentrism, Retrograde Motion
- Kepler’s Laws of Planetary Motion
- Newton’s Laws of Motion
- Newton’s Law of Universal Gravitation
- Einstein’s View of Gravity
- Science
- Pseudoscience and Nonsense(-science)