Today

• Announcements:
  – HW#10 is due Wednesday Nov. 23.
  – Extra credit project on Intelligent Design is available it will be due Dec. 2nd at 5:00pm. Please don’t wait till the last minute.

• Review of Big Bang

• The topics for today are Entropy, Black holes, Worm holes, and time.
Timeline of the Big Bang

- All Forces unified
- Light elements form
- Microwave image formed
- Carbon made
The existence of an unknown scalar field caused the rapid inflation of the Universe.
Big Bang Timeline (the early moments)

![Big Bang Timeline Diagram](image_url)
Map of the microwave sky

WMAP observatory
What we have learned from WMAP

- The Universe is 13.7 billion years old
- The Universe is Flat and will continue to expand forever – The mass of the universe is at the “critical mass”.
- The Universe is made of mostly an unknown form of matter and an unknown form of energy (dark)
What is the Ultimate Fate

- $10^{100}$ years – all the stars will have used their fuel
- $10^{100}$ to $10^{150}$ years “dark ages”
- $10^{150}$ years all black holes will have evaporated
- $10^{1000}$ years the Universe will reach its lowest energy state
- The current age of the Universe is 13.7 billion years $10^{10}$ years
Conservation of Energy

In nature certain quantities are “conserved”. Energy is one of these quantities.

Example: Ball on a hill

A 1.00 kg ball is rolled toward a hill with an initial speed of 5.00 m/s. If the ball roles without friction, how high, h, will the ball go?

\[ KE = \frac{1}{2} mv^2 \quad PE = mgh \; ; \; g = 9.80 \frac{m}{s^2} \]

\[ \frac{1}{2} mv^2 = mgh \rightarrow h = \frac{v^2}{2g} = \frac{(5 \frac{m}{s})^2}{2 \cdot 9.80 \frac{m}{s^2}} = 1.28 \; m \]
The velocity to completely escape the gravity of a planet is:

\[ KE(\text{leaving}) = PE(\text{far away}) \]

\[ \frac{1}{2} mv^2 = \frac{GmM_{\text{planet}}}{R_{\text{planet}}} \]

\[ v = \sqrt{\frac{2GM_{\text{planet}}}{R_{\text{planet}}}} \]

The escape velocity for the Earth is about 11 km/s. See the homework problems for examples.
Large Mass in a small region

What is the escape velocity for an object with the mass of the Sun and a radius of 10 km?

\[ M_{\text{sun}} = 1.99 \times 10^{30} \text{ kg} \quad G = 6.67 \times 10^{-11} \text{ Nm}^2/\text{kg}^2 \]

\[ v = \sqrt{\frac{2GM}{R}} = \sqrt{\frac{2 \cdot 6.67 \times 10^{-11} \cdot 1.99 \times 10^{31}}{10000}} = 5 \times 10^8 \text{ m/s} \]

This is greater than the speed of light!
Black Holes

The “hole” in space is so deep that light cannot escape.
Black Holes

• Black holes act as a lens and we see light from stars behind. They don’t necessarily look “black”.

• They range from 3 solar masses to more than a billion solar masses.
  – Small ones are formed by the collapse of a large star
  – Larger ones form at the center of galaxies

• We can tell they exist because of thing orbiting nothing, and the radiation given off as things fall into them.

• Black holes are not cosmic vacuum cleaners. If the Sun were a black hole (with the same mass) the Earth would still orbit it.
Where do black holes come from?

The fate of a star depends on its mass (size not to scale).
Active Galaxies/ Quasars

At the center is a billion solar mass black hole
Picture of an Active Galaxy (quasar)

Active Galaxy NGC 4438

Hubble Space Telescope WFPC2

NASA and J. Kenney (Yale University)
STScI–PRC00–21
Rotation around a Supermassive Black Hole

Spectrum of Gas Disk in Active Galaxy M87

Hubble Space Telescope • Faint Object Spectrograph
Wormholes
Wormholes

- Wormholes are not stable. Some type of exotic material (that acts as antigravity) is necessary to keep one end open.
- If there are wormholes, there must be white holes. No white hole has ever been observed.
- A white hole would violate the second law of thermodynamics.
The Second Law of Thermodynamics

• Statement: No device can transform a given amount of heat completely into work.
• Statement: The entropy of an isolated system never decreases.
• Statement: Natural process tend to move toward a state of greater disorder.
• Consequence: Time appears to have a direction.
Entropy

• Entropy is a measure of disorder. We usually use the symbol $S$.
• The unit is J/K  \((\text{joules/Kelvin})\)
• Formula: $S = k \ln(W)$, where $k=1.38\times10^{-23}$ J/K and $W$ is the number of possible states of a system.
• Alternative formula: $S = \text{heat}/\text{temperature}$
Two examples

What is the entropy of a deck of cards that has one pair? Data: there are 1,098,240 to order such a deck.

\[ S = 1.38 \times 10^{-23} \text{ J/K} \quad \ln(1,098,240) = 1.92 \times 10^{-22} \text{ J/K} \]

How much is the entropy of a glass of water increased if 1.0 J of heat is added when the water is at 295 K. Assume the temperature rise of the water is small.

\[ S = \frac{1.0 \text{ J}}{295 \text{ K}} = 3.39 \times 10^{-3} \text{ J/K} \]
Coin Tosses

- Suppose we have 20 coins: HHHHHHHHHHHHHHHHH

\[ S = k \ln(1) = 0 \]

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<th>Heads</th>
<th>Number of ways</th>
<th>Entropy (J/K) *10^{-23}</th>
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<tr>
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Why does time always move in one direction?

- Inflation during the Big Bang resulted in a universe that had a very low entropy. Much too low for its size. It is like the Universe started with all heads.
- Hence, everything in the Universe moves toward reaching the correct amount of entropy.
- Time has a direction because going back in time would imply the entropy could be decreased. That is very improbable.
- The Universe tends toward increasing entropy.
- What is time?