# TU130

# Integrated Sciences and Technology

by

Asst. Prof. Dr. Ruangsak Songsathaporn

Department of Physics

Faculty of Science and Technology

Thammasat University

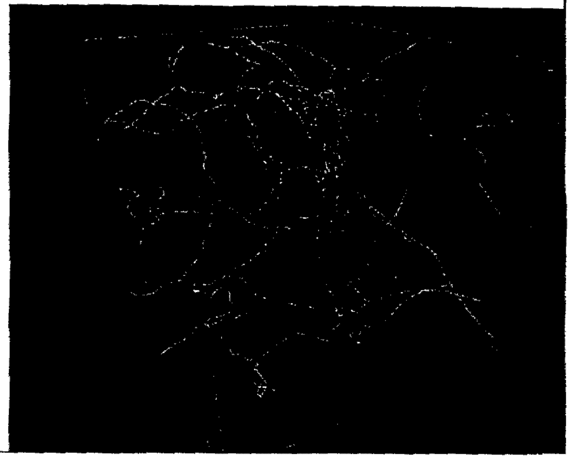
# “Creation of the Universe”

- At about $15 \times 10^9$ years ago the Universe was a dot about the size of one-baht coin called the “singularity”.
- Singularity had infinite density and infinite temperature.

- There was a big explosion called “big bang”.
- Radiation Era

Temperature ~$10 \times 10^9$ K

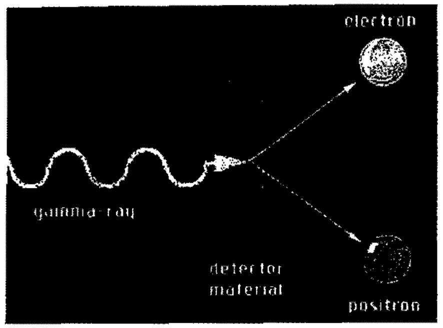
$E = mc^2$



- Energy can be converted into matter.
- When the temperature of the Universe reduced to be ~$1 \times 10^9$ K, no matter can be converted from energy.

- From the big bang to about $10^3$ years after the big bang explosion, the period of time is called “radiation era”.
- In the radiation era, the Universe composed of elementary particles and radiation.

- Pair Production: The conversion of a high-energy gamma-ray into an electron and positron, which are formed simultaneously.



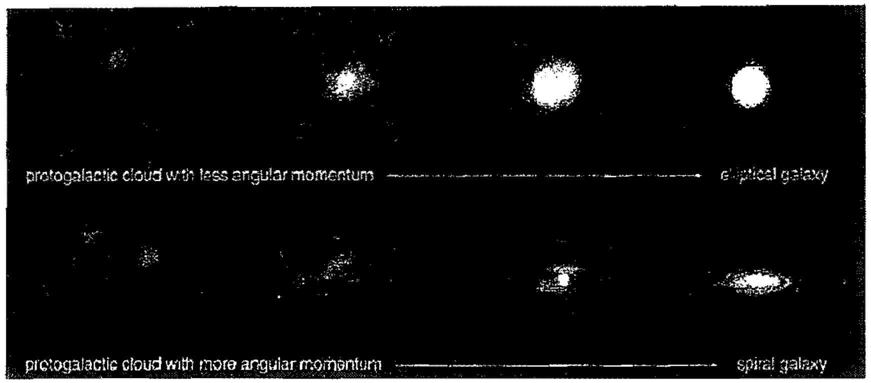

- The combined energy of gamma-rays must be greater than the mass energy of the particle-antiparticle pair.
- About 1,000 years after the big bang, the matter era started.
- Early matter era, the density ~$10^{-13}$ kg/m$^3$ and temperature ~$6x10^4$ K (K = Kelvin).

## "Creation of Atoms"

- Hydrogen atom was created about 100 seconds after the big bang.
- Helium atom was created about 2 minutes after the big bang and the temperature of the Universe at that moment was about $900x10^6$ K.

- Galactic Epoch: the period of galaxy formation that is about $10^6$ to$10^9$ years after the big bang.
- Stellar Epoch: the period of star formation in the galaxy, this period is about $10^9$ to more than $10^{10}$ years after the big bang.

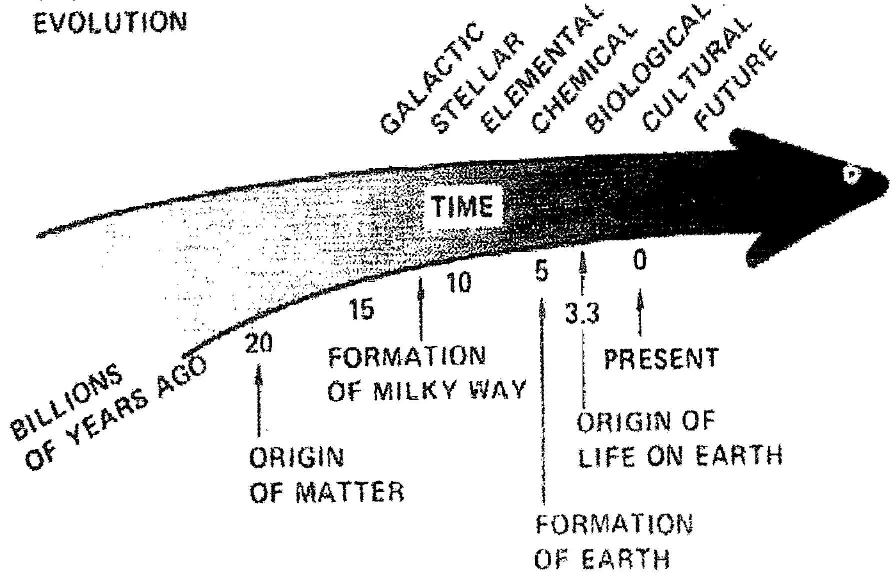
- Galaxy Formation




- Stellar Formation (Case I)

- Stellar Formation (Case II)

COSMIC EVOLUTION



# “Life in the Universe”

- Are we alone?

- What are the characteristics of life?
- Growth (metabolism)
- Reproduction (heredity)
- Movement
- Response to stimuli
- Death

- Do we have any direct evidence that life could have developed from non-living molecules?

- The answer is “yes”.

- The smallest and simplest entity that sometimes appears to be alive is a virus (virus is the Latin word for “poison”).

- All viruses are smaller than the size of a typical modern cell.

- Some viruses are made of only a few thousand atoms.

- Viruses seem to bridge the gap between cells that are living and molecules that are not.

- Viruses contain some proteins and genetic information (in the form of DNA) - none of the material by which living organisms normally grow and reproduce.

  [DNA (deoxyribonucleic acid)]: A nucleic acid that contains the genetic information found in most organisms]

- How can a virus be considered alive?

- When alone, it cannot
- A virus is absolutely lifeless when isolated from living organisms.
- But when the virus gets inside a living system, it has all the properties of life.

- Viruses come alive by transferring their genetic material into living cells.

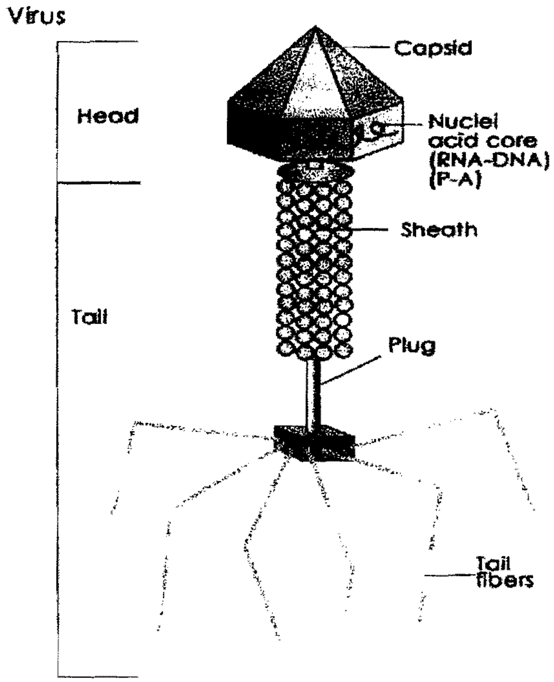
- The genes of a virus seize control of a cell and establish themselves as the new master of chemical activity.

(gene: a unit of heredity)

(genome: the total genetic makeup of an organism. The human genome is all the DNA normally contained in a human cell.)

- Viruses grow and reproduce copies of themselves by using the genetic machinery of the invaded cell, often robbing the cell of its usual function.

- Some viruses multiply rapidly and widely, spreading the disease and eventually killing the invaded organism.




Structure of a virus.

# "Intelligent Life in the Galaxy"

- We look for life beyond out solar system, in the Milky Way and in other galaxies.
- SETI: search for extra-terrestrial intelligence.

---

- The pioneering program was Frank Drake's Ozma Project of 1960.
- In 1983 a long-term SETI program began, financed by NASA.

---

## The Drake's Equation

| | | (1) | | (2) |
|---|---|---|---|---|
| Number of Technological, Intelligent civilizations now present in the Milky Way. | = | Rate of star formation, averaged over the lifetime of the Galaxy. | x | Fraction of those stars having planetary systems. |

---

| | (3) | | (4) | | (5) |
|---|---|---|---|---|---|
| x | Average number of planets within those planetary systems that are suitable for life. | x | Fraction of those habitable planets on which life actually arises. | x | Fraction of those life-bearing planets on which intelligence evolves. |

⑥ Fraction of those intelligent-life planets that develop technological society.

x

⑦ Average lifetime of a technological competent civilization.

x

- Rate of star formation
  - Now there are at least $100 \times 10^9$ stars shine in the Milky Way.
  - Lifetime of the Milky Way $\sim 10 \times 10^9$ years

$$\text{Rate of star formation} = \frac{100 \times 10^9 \text{ stars}}{10 \times 10^9 \text{ years}} = 10 \text{ stars/year}$$

- Fraction of stars having planetary systems.
  - Many astronomers believe planet formation result of the star-formation process.
  - Is there any direct evidence for planets in orbit around other stars?
  - Yes.

- The theory of star-formation is called the condensation theory.

- Accepting the condensation theory and its consequences the astronomers believe that essentially all stars have planetary systems.

- Fraction of stars having planetary systems ~1
- Number of habitable planets per planetary system
- It is found that temperature, more than any other single quantity, determines the feasibility of life on a given planet.

- The surface temperature of a planet depends on two things:

1. The planet's distance from its parent star.
2. The thickness of its atmosphere

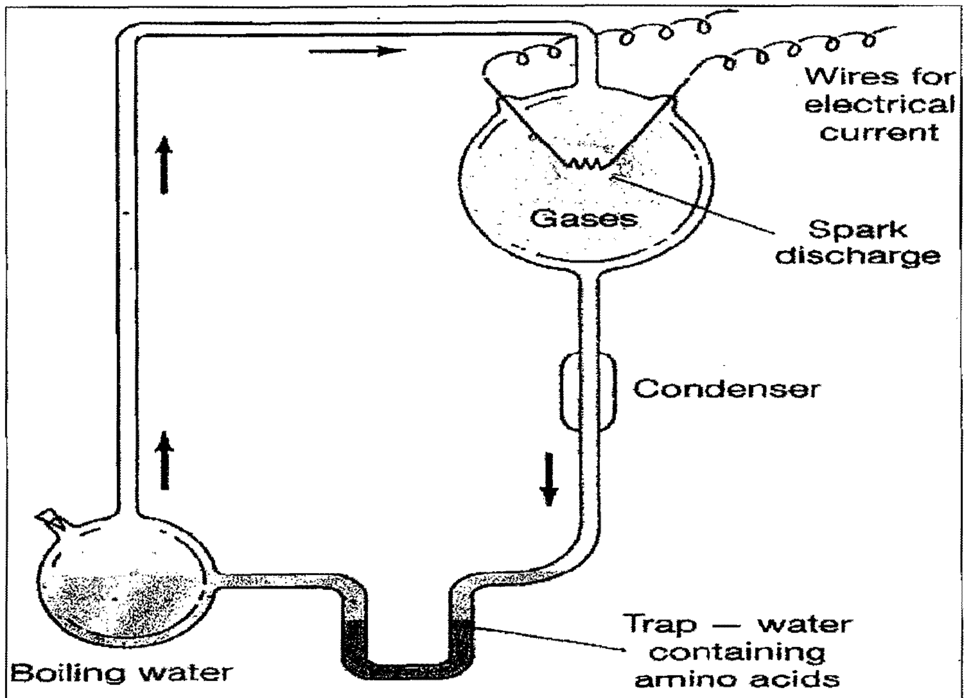
- Taking all these factors, we assign a value of 1/10 to this term in Drake's equation.
- Fraction of habitable planets on which life arises.

- Laboratory experiments seem to suggest that certain chemical combinations are strongly favored over others: synthesization of amino acids.

(amino acids: The basic building blocks of all polypeptides and proteins. 20 common amino acids are found in proteins.)

(Polypeptide: A single chain of amino acids. It is differentiated from a protein only by its smaller size and relative lack of complexity).

- In 1953, Urey and Miller designed an chemical experiment which allowed them to synthesize the amino acid from some gases in nature.






- To assign a value close to 1 is to believe that life is inevitable, given the proper ingredients, a suitable environment and a long enough period of time.

- So we will take the optimistic view and adopt a value of 1.

- Fraction of life-bearing planets on which intelligence arises.
- Biological evolution through natural selection is a mechanism that generates intelligence.
- We will be optimistic and adopt a value of 1.

- Fraction of planets on which intelligent life develops and uses technology.
  - We need to estimate the probability that intelligent life eventually develops technological competence.
  - Technology is inevitable.
  - Why haven't other life-forms on Earth also found technology useful?

- Possibly the competitive edge given by intellectual and technological skills to humans, the first species to develop them.
- Some species will probably always fill the niche of technological intelligence that we will take this term to be close to 1.

- Average lifetime of a technological civilization.
  - The longevity of technological civilization is unknown (from other planets).
  - Only human civilization is known.
  - If civilizations typically survive for 1000 years.
  - The last term of Drake's equation should be 1000.

Number of technological intelligent civilizations now present in the Milky Way

① ② ③ ④ ⑤ ⑥ ⑦

$= 10 \times 1 \times 0.1 \times 1 \times 1 \times 1 \times 1000$

$= 1000$

Number of technological intelligent civilizations now present in the Milky Way = The average lifetime of a technologically competent civilization (in years)

## "Determination of the Age of the Earth"

- How old is the Earth?
- In 1664 Bishop James Ussher of the Church of Ireland based solely upon his personal interpretation of Biblical texts, placed the Creation on 26 October, 4004 BC, at 9:00 AM.

- As the evidence for vast periods of geological time became more and more persuasive during the 18th century, opinions on this issue became institutionalized under two principal schools of thought.

- First, those who accepted the Ussher interpretation of biblical chronology attributed the abrupt endings of geological ages to the domination of a handful of catastrophic events (in extreme cases, only the single event of Noah's flood) that did virtually all the work of laying down the kilometers of sediment in the geological record.

These Catastrophists began with the conclusion that Earth is really only a few thousand years old. Fossils were often dismissed by Catastrophists as the remains of "that accursed race which perished with the Flood" or as artifacts made by Satan to mislead us or by God to "test our faith".

- At the other extreme were those geologists who accepted that these vast thicknesses of sediments took many millions of years to be deposited.

- This view gave rise to the Uniformitarian school, which attributed all the work of geology to very slow, unspectacular processes working over vast periods of time.

- The Uniformitarians denied the reality of global catastrophes, which smacked of magic and seemed intended not to explain the observational data, but to provide an excuse for disregarding the data.

- The debate was both sharpened and heated in the mid-1860s by Charles Darwin's work on the origin of biological species. (species: A group of organisms that resemble each other and are generally able to interbreed and produce fertile offspring.)

- Darwin proposed that the proliferation of species occurred as the combined effect of two main factors, chance isolation of populations and natural selection.

- The Darwinian explanation for the fossil record emphasized migration or division of preexisting species by slow geological change to establish independent gene pools that initially differed only slightly. In these smaller, isolated populations, combinatorial variation of existing genes played out different roles in different environments, where the criteria for survival were different.

A trait that is useful to a jungle gene pool might be irrelevant to a grassland gene pool and harmful in a desert setting; therefore, differing environments will favor different traits and lead to genetic divergence even if the original gene pools were identical. Further, mutations occurring randomly and independently within these separate gene pools lead inevitably to genetic drift.

(Mutation: Any change in the DNA of an organism. Most mutations are deleterious but are often recessive. Beneficial mutations may increase in the population due to natural selection. The spontaneous mutation rate is quite low (on the order of one in a million to one in a trillion). ($10^{-12}$) Three major sources of mutational damage to DNA are high-energy radiation such as X-rays that cause physical breakage, low-energy radiation such as UV light that creates DNA cross-links,and chemical modification of DNA bases. The latter two ultimately lead to replication errors.)

- Most mutations are harmful or nonfunctional, many are lethal, and only a few will confer some functional advantage on their carriers. Individuals with helpful mutations will tend to be more successful and leave more offspring, and hence these new traits will tend to spread throughout the local breeding population.

- After a series of such mutations, the different populations will cease to be able to interbreed and will become separate species.

- The natural time scale for such divergence of a cluster of species from a common ancestor by this process of natural selection is on the order of $10^5$ to $10^6$ years.

(Natural selection: The process by which organisms well adapted to their environment survive to produce offspring while those more poorly adapted may not. In this way, particular combinations of genes are propagated differentially. According to Darwinism, natural selection acting on a varied population results in evolution.)

- By observing the succession of plants and animals, geologists developed "sequence-geochronology".

- Geologists and paleontologists at that period estimated the time required for such sedimentation to be around 100 to 400 million years.

- Lord Kelvin calculated how long it would have taken a body the size of the Earth to cool from an initially molten state to its present temperature.

- Kelvin found the age of the Earth to be 20 to 40 million years.

- The age of the Earth found by Kelvin was wrong because the rate of cooling of the Earth is much more slower than expected by Kelvin.

- Kelvin knew nothing about the heat released from the radioactive substances inside the Earth.

- This due to radioactivity

- Becquerel discovered radioactivity (Radioactivity: The spontaneous transformation of one atomic nucleus into another with the emission of energy. The energy is released in the form of an energetic particle, usually an alpha particle, beta particle, sometimes accompanied by a gamma-ray photon. The unstable isotopes of an element that can undergo such transformations are called radioactive isotopes, or radioisotopes. The emission of a particle from the nucleus of a radioisotope of a different element, as in the beta decay of carbon-14 to nitrogen-14. The isotope produced is itself often radioactive. The average time taken for half a given number of nuclei of a particular radioisotope to decay is the half-life of that radioisotope; values range from a fraction of a second to thousands of millions of years.)

- The modern quantitative study of the history of the Earth and its life dates back only a few decades. The German physicist C.F. von Weizsacker proposed the principle underlying potassium-argon dating in 1937.

- The radionuclide $^{40}K$ decays to $^{40}Ar$, a stable isotope of the noble gas argon. The half-life for this decay is $1.25 \times 10^9$ years. A measurement of the ratio of $^{40}K$ to $^{40}Ar$, as found in the rock in question, can be used to calculate the age of that rock.

$$t\lambda = \ln(1+(N_{Ar}/N_K))$$

$\lambda$ = the half-life

$(N_{Ar}/N_K)$= the ratio of $^{40}Ar$ to $^{40}K$

- In the 1940s the U/Th-He technique was introduced to be another method to determine the age of the Earth.

- U-238 series (Uranium-238)

$^{238}U_{92}$ (called parent meterial)

↓ $\alpha$ (alpha decay)

$^{234}Th_{90}$ (Thorium called daughter product)

↓ $\beta$ (beta decay)

$^{234}Pa_{91}$ (Protactinium another daughter product)

↓ $\beta$

$^{234}U_{92}$

↓ $\alpha$

$^{230}Th_{90}$

↓ $\alpha$

↓

$^{226}Ra_{88}$ (Radium)

↓ α

$^{222}Rn_{86}$ (Radon)

↓ α

$^{218}Po_{84}$ (Polonium)

↓ α

$^{214}Pb_{82}$ (Plumbum- Latin word for lead)

↓ β

$^{234}Bi_{83}$ (Bismuth)

↓ β

↓

$^{214}Po_{84}$ (Polonium)

↓ α

$^{210}Pb_{82}$

↓ β

$^{210}Bi_{83}$

↓ β

$^{210}Po_{84}$

↓ α

$^{206}Pb_{82}$ (Lead-206 called the end product)

- The half-life of U-238 is $4.5 \times 10^9$ years.
- Lead consists of several different isotopes, not all of them produced by radioactivity (radiogenic material).

- $^{204}Pb_{82}$ is a non-radiogenic.

$^{238}U_{92} \longrightarrow {}^{206}Pb_{82}$ (half-life = $4.5 \times 10^9$ yrs.)

$^{232}Th_{90} \longrightarrow {}^{208}Pb_{82}$ (half-life = $1.4 \times 10^{10}$ yrs.)

- If common non-radiogenic lead- 204 and the radiogenic lead-206 and lead-207 are added together, excessive ages are obtained.

- In 1917 J. Barrell of Yale University tried to solve the problem by using only samples in which no non-radiogenic lead-204 is present.

- Barrell got the age of the Earth to be about $1.8x10^9$ years which was wrong because of the impurity of his samples.

- There are no differences in chemical characteristics between the isotopes of a given chemical element, the only differences are very small variations in mass.

- In order to solve this problem the scientists need a special equipment called "mass spectrometer" which in the 1930s, a physicist named A.O.C. Nier at the University of Minnesota was the one who was able to make a perfected mass spectrometer.

- Then in the year 1956, C. Patterson of the California Institute of Technology got an approximate age for the Earth and the solar system to be $(4.55 +/- 0.07)x10^9$ years.

- G. Tilton with his colleague R.H.Steiger and others made some refinements in the techniques and got the currently accepted age of the Earth to be about $4.57x10^9$ yrs.

- Other methods to determine the age of the Earth Rubidium-87 Strontium-87 (The half-life is 48.8x10$^9$ years) Potassium-40 Argon-40 (The half-life is 1.25x10$^9$ years)

- If you know the half-life of a given radionuclide, you can in principle use the decay of that radionuclide as a clock to measure time intervals. The decay of very long-lived nuclides, for example, can be used to measure the age of rocks - that is, the time that has elapsed since they were formed. Such measurements for rocks from Earth and the moon, and for meteorites, yield a consistent maximum age of about 4.5x10$^9$ years for these bodies.

- $^{87}Rb_{37}$ - $^{87}Sr_{38}$ method gave the age of the Earth to be (4.6 +/-0.1)x10$^9$ years.

- For measuring shorter time intervals, in the range of historical interest, radiocarbon dating has proved invaluable. The radionuclide $^{14}C$ (with half-life = 5730 years) is produced at a constant rate in the upper atmosphere as atmospheric nitrogen is bombarded by cosmic rays. This radiocarbon mixes with

the carbon that is normally present in the atmosphere (as $CO_2$) so that there is about one atom of $^{14}C$ for every $10^{13}$ atoms of ordinary stable $^{12}C$. Through biological activity such as photosynthesis and breathing, the atoms of atmospheric carbon take places randomly, one atom at a time, with the atoms of carbon in every living thing, including mushrooms, penguins and humans.

Eventually an exchange equilibrium is reached at which the carbon atoms of every living thing contain a fixed small fraction of the radioactive nuclide $^{14}C$. This equilibrium persists as long as the organism is alive. When the organism dies, the exchange with the atmosphere stops and the amount of radiocarbon trapped in the organism, since it is no longer being replenished, dwindles away with a half-life of 5,730 years.

By measuring the amount of radiocarbon per gram of organic matter, it is possible to measure the time that has elapsed since the organism died. Charcoal from ancient campfires, the Dead Sea scrolls and many prehistoric artifacts have been dated in this way. The age of the scrolls was determined by radiocarbon dating a sample of the cloth used to plug the jars in which the scrolls were sealed.

- This carbon-14 method of dating was developed by W.F.Libby in 1952.
- Carbon-14 dating applies only to deposits younger than about 40,000 years. (special techniques will take it back to 70,000 or perhaps 100,000 years)