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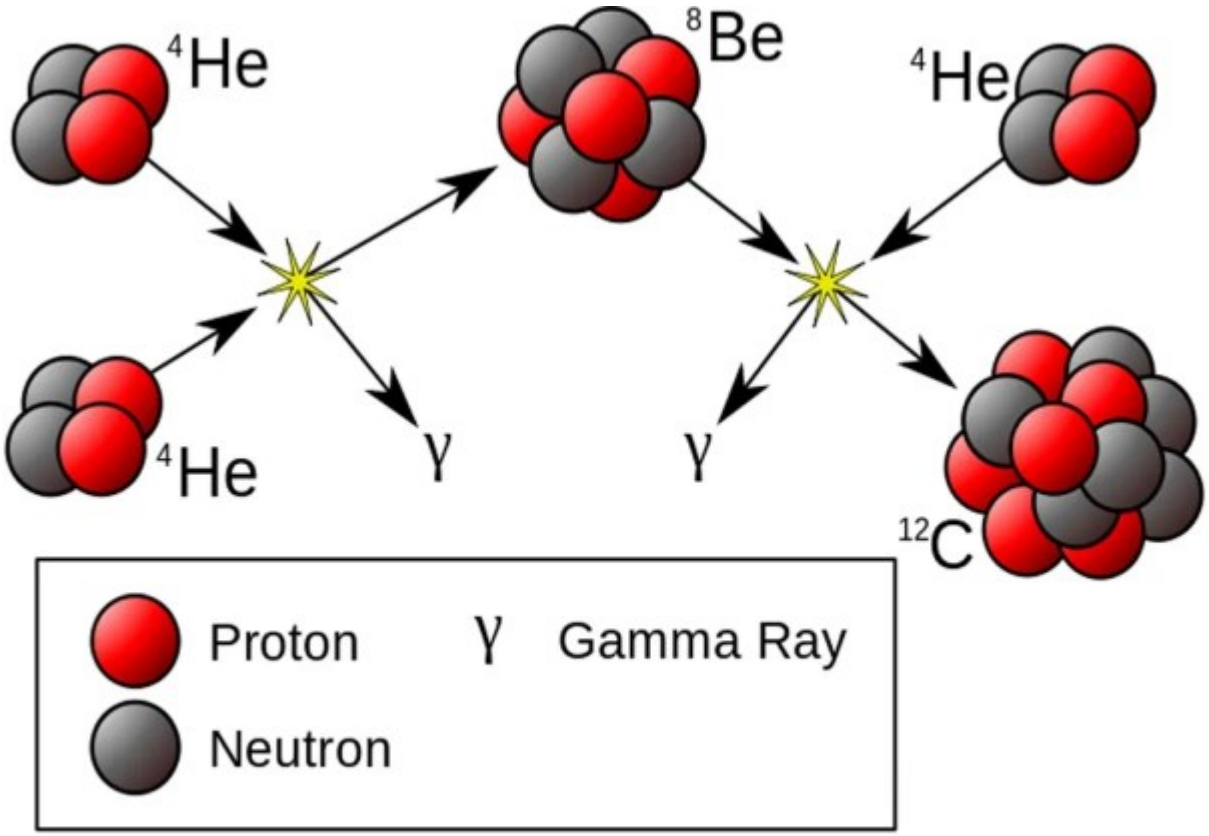


The Triple Alpha Collision Process: the excited nuclear energy level of unstable Beryllium-8 matches an excited energy level of carbon-12 to create a resonance enhancement for the rare triple collision—so we get carbon/biochemistry

"Scientists are slowly waking up to an inconvenient truth – the universe looks suspiciously like a fix. The issue concerns the very laws of nature themselves. For 40 years, physicists and cosmologists have been quietly collecting examples of all too

convenient "coincidences" and special features in the underlying laws of the universe that seem to be necessary in order for life, and hence conscious beings, to exist."
—Paul Davies,

" The argument (the Anthropic Principle) can be used to explain why the conditions happen to be just right for the existence of (intelligent) life on the earth at the present time. For if they were not just right, then we should not have found ourselves to be here now, but somewhere else, at some other appropriate time."
—Roger Penrose,

"One doesn't show that something doesn't require explanation by pointing out that it is a condition of one's existence. If I ask for an explanation of the fact that the air pressure in the transcontinental jet is close to that at sea level, it is no answer to point out that if it weren't, I'd be dead."
—Thomas Nagel, Mind and Cosmos.

"A common sense interpretation of the facts suggests that a super-intellect has monkeyed with physics, as well as with chemistry and biology, and that there are no blind forces worth speaking about in nature. The numbers one calculates from the facts seem to me so overwhelming as to put this conclusion almost beyond question."
—Fred Hoyle

SECTION 1: General Considerations

1.1 SOURCES

Some of the material in this section is drawn from a post on my blog, Philosophic Issues in Cosmology 6, summarizing an article by George F.R. Ellis. The Anthropic Principle has been discussed extensively in books and articles. There is a concise summary by Robert Koons in

his philosophy lectures, giving various interpretations, with arguments for and against each. (I'll summarize some of these below.) A good collection of articles with different (and opposing views) of the Anthropic Principle is given in "God and Design" (editor, Neil Manson). Possibly the best web source on physics and cosmology is the 2013 article by Stephen Barr, Anthropic Coincidences and the Multiverse Idea, (You could read that and skip this piece—but I wouldn't want you to do that, would I?) A more extended recent review, including critiques of "anti-anthropic" articles, has been given by Luke Barnes, Finally, the British Astronomer Royal, Sir Martin Rees, has consolidated the anthropic coincidences into six dimensionless parameters, "Just Six Numbers," values of which have to be narrowly limited for a universe such as ours to exist.

There are many versions of the Anthropic Principle ranging from the Weak Anthropic Principle, WAP, which tautologically observes that if the universe weren't fit for us to be here we would wouldn't be here discussing the principle (see the Penrose quote above), through the Strong Anthropic Principle, SAP, that the universe has been fine-tuned for intelligent life (us), on up to the Completely Ridiculous Anthropic Principle (by Martin Gardner—you complete the acronym).

1.2 THE INTERPRETATION OF GEORGE F.R. ELLIS

George F.R. Ellis, a South African astrophysicist, a winner of the Templeton Prize and a prolific author on cosmology and its relation to religious belief, has written a fine article on philosophic issues in cosmology. In his presentation of the anthropic coincidences, he focuses on the special nature of physical laws that allow for the presence of life, rather than on their improbability (all quotes are from the linked article):

> "*One of the most profound issues in cosmology is the Anthropic question…why does the Universe has the very special nature required in order that life can exist? The point is that a great deal of "fine tuning" is required in order that life be possible. There are*

> *many relationships embedded in physical laws that are not explained by physics, but are required for life to be possible; in particular various fundamental constants are highly constrained in their values if life as we know it is to exist…What requires explanation is why the laws of physics are such as to allow this complex functionality (life) to work. …We can conceive of universes where the laws of physics (and so of chemistry) were different than in ours. Almost any change in these laws will prevent life as we know it from functioning."*

Ellis posits as a first requirement for the laws of physics "*the kind of regularities that can underlie the existence of life:*" laws that are not based on symmetry and variational principles are unlikely to produce the kind of complexity that would be required for life. He also sets up general conditions that allow for organic life and cosmological boundary/initial conditions. In this respect he cites the following as necessary:

> "Quantization that stabilizes matter and allows chemistry to exist through the Pauli exclusion principle;
> The number D of large spatial dimensions must be just 3 for complexity to exist.
> The seeds in the early universe for fluctuations (quantum fluctuations) that will later grow into galaxies must be of the right size that structures form without collapsing into black holes…
> The size of the universe and its age must be large enough…we need a sufficiently old universe for second generation stars to come into existence and then for planets to have a stable life for long enough that evolution could lead to the emergence of intelligent life. Thus the universe must be at about 15 billion years old for life to exist.
> There must be non-interference with local systems. The concept of locality is fundamental, allowing local systems to function effectively independently of the detailed structure of the rest of the Universe. We need the universe and the galaxies in it to be largely empty, and gravitational waves and tidal forces to be weak enough, so that local systems can function in a largely isolated way.
> The existence of the arrow of time, and of laws like the second law of thermodynamics,

> are probably necessary for evolution and for consciousness. This depends on boundary conditions at the beginning and end of the Universe.
> Presumably the emergence of a classical era out of a quantum state is required. The very early universe would be a domain where quantum state is required. The very early universe would be a domain where quantum physics would dominate leading to complete uncertainty and an inability to predict the consequence of any initial situation; we need this to evolve to a state where classical physics leads to the properties of regularity and predictability that allow order to emerge.
> The fact that the night sky is dark…is a consequence of the expansion of the universe together with the photon (light particle) to baryon (mass particle) ratio. This feature is a necessary condition for the existence of life: the biosphere on Earth functions by disposing of waste energy to the heat sink of the dark night sky. Thus one way of explaining why the sky is observed to be dark at night is that if this were not so, we would not be here to observe it.
> Physical conditions on planets must be in a quasi-equilibrium state for long enough to allow the delicate balances that enable our existence, through the very slow process of evolution, to be fulfilled."

There are a number of other constraints, limited values for forces—gravity, electromagnetic, weak nuclear, strong nuclear—and fundamental constants, including that for particle masses and number of particles that are needed for life to evolve. In summary, Ellis puts the Anthropic Principle as the following:

> "Life is possible because both the laws of physics and the boundary conditions for the universe have a very special nature. Only particular laws of physics, and particular initial conditions in the Universe, allow the existence of intelligent life of the kind we know. No evolutionary process whatever is possible for any kind of life if these laws and conditions do not have this restricted form."

1.3 THE INTERPRETATION OF ROBERT KOONS

Robert Koons, a philosophy professor at the University of Texas, summarizes some general objections to invoking the Anthropic Principle for carbon-based life

1. The problem of “old evidence”;
2. Laws of nature don’t need to be explained;
3. We had to be here in any event (see Penrose’s quote above);
4. Exotic life might exist;
5. The Copernican Principle–rejection of anthropocentricity is fundamental to science;
6. We’re only one among many universes (see below).

Objection 1 can be countered by the argument that such evidence is used frequently in science when direct experiments can’t be done–witness the General Relativity explanation of the advance in the perihelion of Mercury.

Objection 2 would do away with all interpretations of theory, quantum mechanics, and the philosophy of science.

Objection 3 is countered as in Thomas Nagel’s quote above; we are an information-seeking life form that needs explanations.

Objection 4 is invalid–we’re talking about conditions for carbon-based life; science-fiction can explore and has explored conditions for exotic life.

Objection 5–the Anthropic Principle was introduced to rebut the Copernican Principle

.Objection 6–the multiverse proposition is not itself proven.

Here’s why a multiverse is invoked by atheistic cosmologists: if infinitely many universes with

potentially different physical laws and constants exist, then it is not unlikely that in all these, one universe with appropriate conditions for life would be present. The analogy is like that of having a lottery ticket with the numbers 11111 be the winner. That combination of numbers looks improbable, but since there are a whole host of numbers from 00000 to 99999, it is no less probable than any other number. Accordingly the notion of special Creation, consistent with the anthropic coincidences, is not necessary and one piece of evidence for a Creating God is done away with.

This argument leads us to the next Sections: the evidence for the anthropic principle; is there a probability to our universe? I put this evidence, the so-called "Anthropic Coincidences" into categories corresponding to types of of science. This sorting is to some extent arbitrary; cosmology, particle physics, chemistry, molecular biology are interdependent, linked together by fundamental theory.

SECTION 2: Our "Goldilocks Universe"— The "Just Right" Anthropic Coincidences of Cosmology

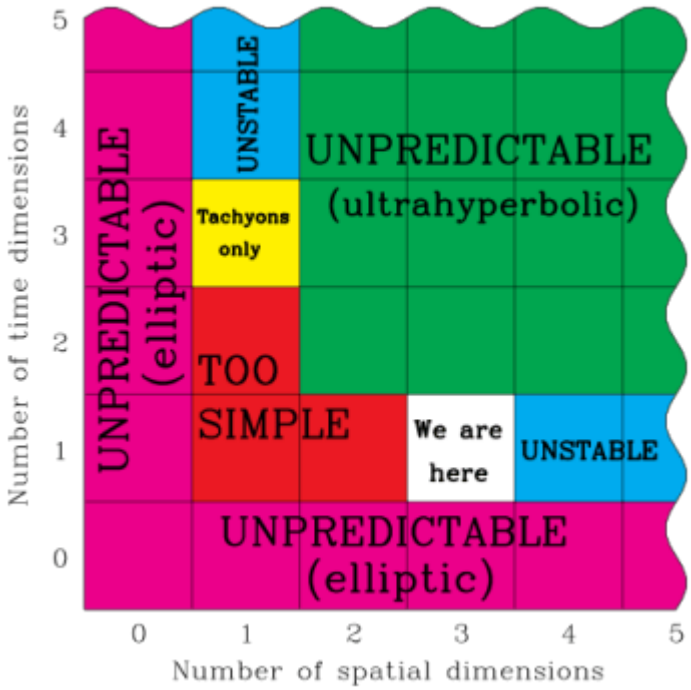
2.1 CAUTIONARY THOUGHTS

Let me emphasize again that citing these anthropic "coincidences" separately does not mean they are independent. One should not imagine, for example, that God picked out a value for the excited energy level of carbon-12 nuclei tp enable carbon-12 syntheses, and then, in a separate action, picked out laws for electromagnetic and gravitational forces to enable star formation. All the events covered by the term "anthropic coincidence" are jigsaw puzzle pieces in one big picture, a "TOE," Theory of Everything, crafted by God, the Grand Designer. Accordingly, it is a serious error to attempt to assign separate probabilities to individual coincidences and then multiply them together to get an overall probability for the universe (but see below, SECTION 4, "Is there a Probability for the Universe?"). Finally, the items listed below are by no means the only anthropic coincidences; they are selected as important

representative examples.

2.2 “JUST RIGHT” COSMOLOGY—THE EXPANDING UNIVERSE

Here are general features of our universe that enable carbon-based life to exist, taken from Chapter 15 of “Modern Physics and Ancient Faith,” by Prof. Stephen Barr and from “Faith, Science and Understanding” by Rev. Dr. John Polkinghorne, FRS:



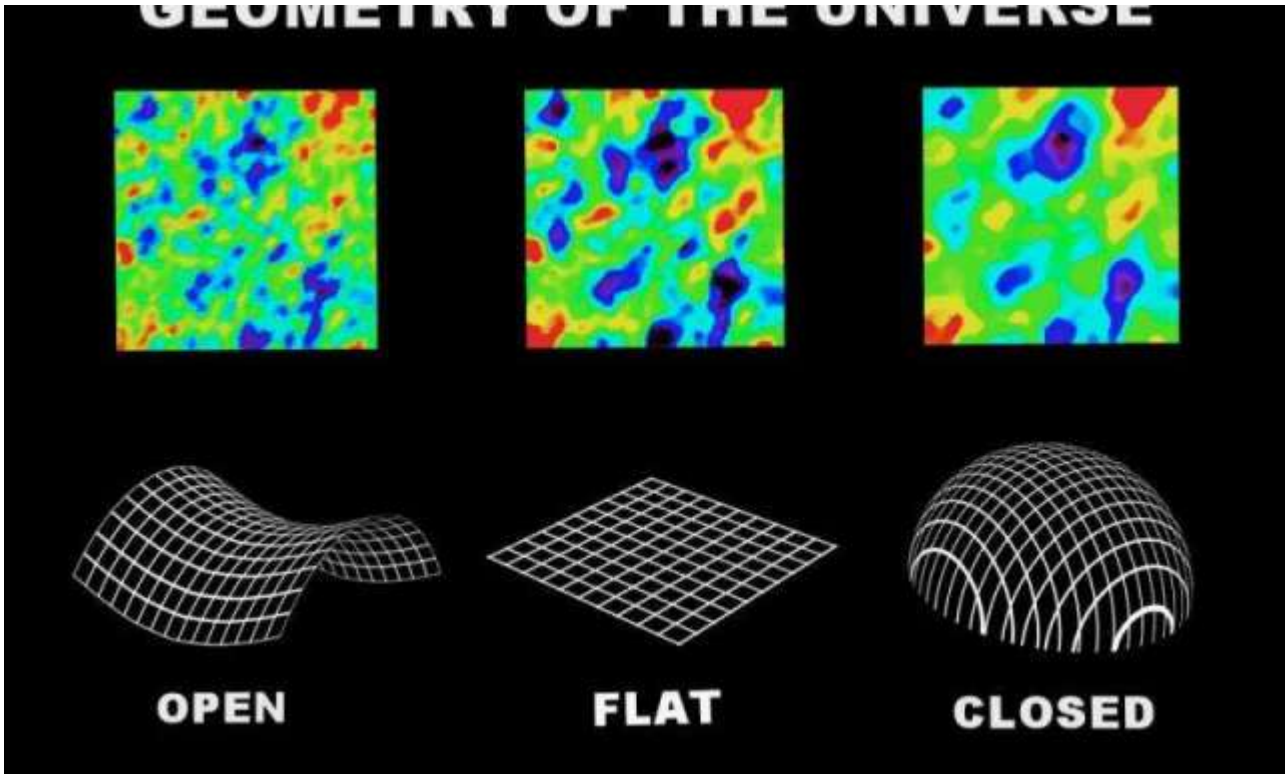
Spacetime dimensions compatible with carbon-based life. (by Max Tegmark) from Wikimedia Commons

Spacetime Dimensionality must be 4 (3 space, 1 time). See the illustration at the left. The “unpredictable” regions have to do with force laws—gravity, electromagnetism–having a different form and thereby unstable planetary orbits. The “too simple” have to do with problems of connectivity: for example two lines will always intersect in space dimensions less than three—you can’t have one line (e.g. a nerve or blood vessel) go over another line.

Expansion of the Early Universe. The early universe expanded at just the right rate; if it had expanded faster, then matter would have been too sparse to come together to form stars and galaxies; if it had expanded slower, matter would have

been too dense, and the universe would have contracted in a “crunch.” (See below about “Flat Spacetime,” and ESSAY 2, Section 2.6, “The Flatness Problem.”)

Flat Spacetime and the Density Parameter, Ω. The theory of General Relativity predicts that matter/energy yields a curvature in space-time. This curvature can be positive (as in a sphere), zero (as in a flat plane, a table top), or negative (as in a saddle). The amount of curvature depend on the density of matter and energy (see here and Science Background, Section 3 for a detailed explanation), This density is given as a relative quantity, Ω, the ratio of the actual density to a “critical density”—the density for which spacetime is flat. Accordingly, for a flat spacetime. Ω = 1 exactly. Measurements of fluctuations in the cosmic microwave background radiation (CMBR) give clues about which curvature exists, as shown by the illustration below.



Cosmic Microwave Background Radiation (from WMAP) for different spacetime curvatures.
from Wikimedia Commons

The inferred value of Ω from WMAP CMBR measurements is 1.02 +/- 0.02, corresponding to a flat spacetime, as near as can be measured.

The Cosmological Constant, Λ. As stated above, the expansion of the universe depends on the density of matter and energy; the matter consists of matter that can be detected experimentally and so-called "dark matter. A major contribution to the total density (almost 70%) is dark energy, energy that does not radiate. This dark energy is characterized by the parameter Λ (Greek upper case "lambda"), "The Cosmological Constant."

Einstein introduced Λ as a fudge factor in his paper on general relativity: he needed this parameter to yield a static, time-independent, stable universe as a solution to the general relativity equations, rather than one that would expand or contract. Later he said that this was his biggest scientific mistake. But even this mistake has turned golden. As stated above, Λ is now referred to as the "Cosmological Constant," which quantifies the mysterious "dark energy" that is responsible for most of the expansion of the universe, a fudge factor if you will, but one of enormous significance.

The Expanding Universe. I hope that the reader will see that the features discussed above—the expansion rate of the universe, the density parameter, Ω, and the cosmological constant, Λ—are inter-related, connected together. One should also note that in the history of the universe expansion, the major sources for the expansion was different at different times:

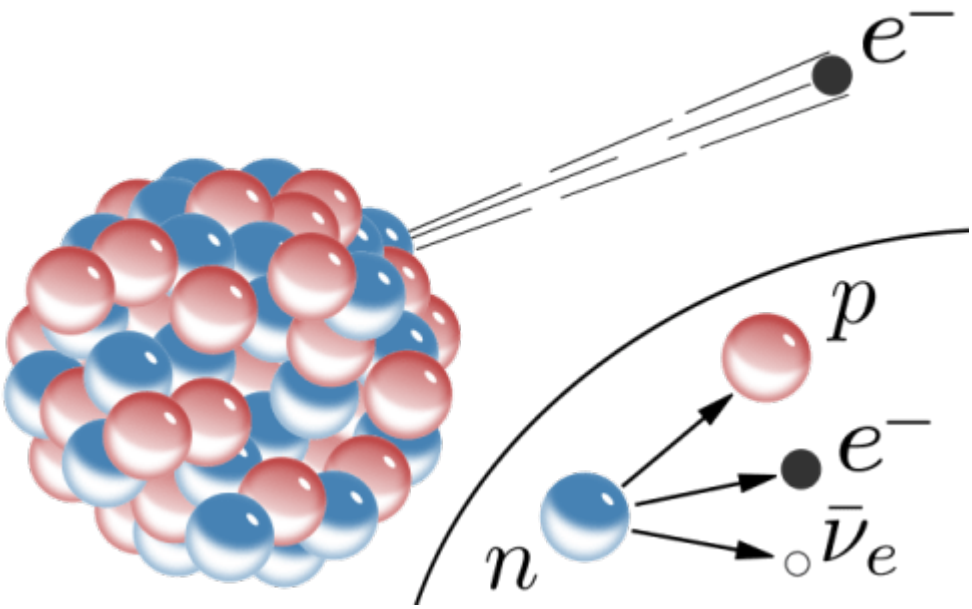
> *"The previous history of the big bang is viewed as being at first radiation dominated, then matter dominated, and now having passed into the era where dark energy is the dominant influence."*
> —Carl Nave, hyperphysics, dark matter

The Age of the Universe. Carbon based life, as we know it would not have existed in a universe only a few billions years old. Why? First, no carbon; it took time for the heavier elements, carbon and beyond, to be formed in the interiors of giant stars and then scattered through the universe by the explosion of stars turned nova and supernova. Second, there would not have been time for life to have evolved into its present state in only a billion years or so.

SECTION 3: The “Just Right” Physics Forces

3.1 THE “JUST RIGHT” WEAK NUCLEAR FORCE

The weak nuclear force is one of the four fundamental forces of nature, electromagnetism, gravity, and the strong nuclear force are the other three. The weak nuclear force is that which plays a role in beta decay, the decay of a neutron to form a protons, an electron, and a neutrino. See the illustration below. Although the adjective “weak” is applied, the weak nuclear force is stronger than gravitation; it is a very short-range force



beta decay: a neutron (n) in a radioactive nucleus decays to form a proton (p), an electron (e-) and an antineutrino (v)
from Wikimedia Commons

The weak force is important in determining the amount of protons and neutrons present in the universe. If it were too strong there would not be the right ratio of protons and neutrons for helium fusion, the slow-burning fuel in stars; the nuclear fusion process would have gone on to end in iron nuclei; stars would have burnt out too quickly for life to have evolved.

The weak force is also important in enabling the formation of supernovas. The periodic table is formed in the interior of giant stars and then spread through the universe when the star explodes in a supernova. If this process had not occurred then life as we know it, with carbon and alll the other elements, could not have existed.

3.2 THE “JUST RIGHT” STRONG NUCLEAR FORCE.

The “strong” nucler force is the force that holds protons and neutrons together to form nuclei of the elements in the universe. Were this force slightly less, only protons would exist; were it slightly greater, no protons, only lifeless heavy elements (and a big crunch?)

3.3 THE “JUST RIGHT” CARBON-12 NUCLEAR ENERGY—THE TRIPLE ALPHA PROCESS.

The element Carbon has two stable nuclei: carbon-12, consisting of 6 neutrons and 6 protons; carbon-13, consisting of 7 neutrons and 6 protons. (The number of protons in the nucleus gives the number of electrons in the neutral atom, which thus determines the chemical properties of the element.) Carbon-11 nucleus is unstable (carbon-11 could be formed from a collision with a stable lithium-7 nucleus and an alpha particle—helium-4 nucleus, 2 neutrons, 2 protons). A Carbon-12 nucleus could in principle be formed from a collision between a beryllium-8 nucleus (4 neutrons, 4 protons) and an alpha particle, but beryllium-8 is unstable; there wouldn’t be enough of it around to yield carbon-12.

What’s the solution? A triple collision (of sorts) between three alpha particles, whence the term “Three Alpha Process.” This “collision” isn’t one where all three alpha particles collide at once; rather, two collide forming a very short-lived beryllium-8 nucleus, which collides with an alpha particle. Ordinarily only a very small fraction of such quasi-triple collisions would yield carbon-12 nuclei.

What might be done to increase the yield of carbon-12? Fred Hoyle predicted that there would be a higher energy state, an energy that had the same value as the lowest energy

("ground") of a beryllium-8 nucleus, or more exactly, of two alpha particles. That these energies are the same gives rise to a quantum mechanical "resonance" effect, where the two alpha particle nuclei can easily tunnel over to the excited, higher energy state of the carbon-12 nucleus. (The term resonance comes from a musical analogy: if you hit a tuning fork tuned at 440 vibrations /sec it will excite a sound in a hollow pipe or a string tuned to that same frequency.) Fred Hoyle's prediction of the carbon-12 nuclear energy,"the Hoyle state," required to account for the presence of carbon-12 in the universe (and the heavier elements derived from carbon-12) was confirmed experimentally by Caltech physicists.

3.4 THE "JUST RIGHT" RATIO OF ELECTRICAL AND GRAVITATIONAL FORCES.

Electrical and gravitational forces follow an "inverse square law," which is to say that the force varies inversely as the square of the distance: if you double the distance between two interacting bodies, the force between them would become 1/4 as great. This law (and the finely tuned values of appropriate fundamental constants) enables a balance between electrical and gravitational forces[1] such that atoms could be formed in the early universe and thence stars and galaxies.[2] If the gravitational force/electrical force ratio had been slightly greater, no elements or atoms would have been formed and the universe would have contracted in a "Big Crunch;" if this ratio had been slightly less, no stars could have formed because of electrical repulsion between protons.

SECTION 4: "Just Right" Planetary and Geological Conditions

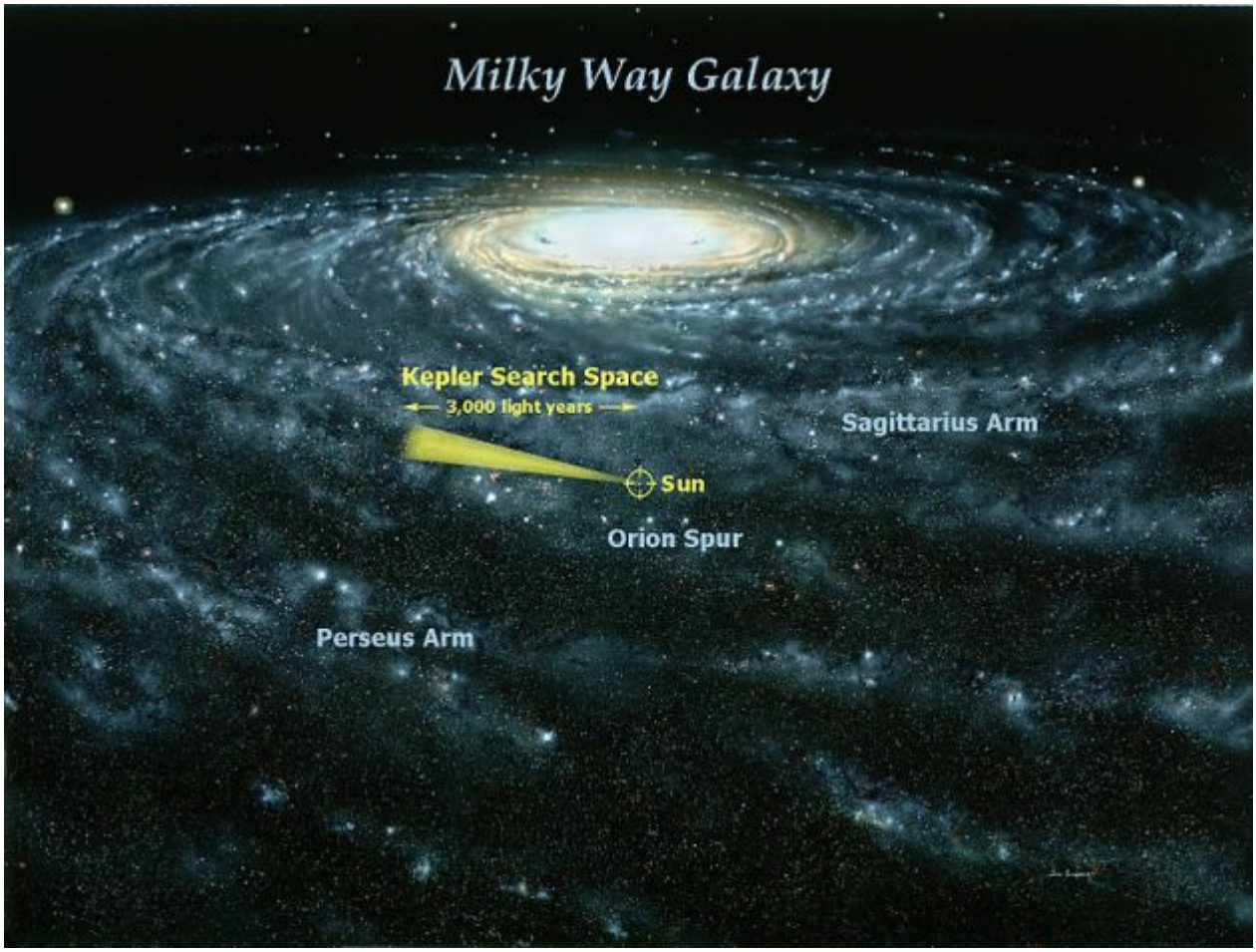
4.1 "JUST RIGHT' PLANETARY AND GEOLOGICAL CONDITIONS IF THE UNIVERSE IS LARGE/OLD ENOUGH.

There are about two trillion galaxies in the observable universe. Each galaxy contains 100 to 300 billion stars. Accordingly, if there is variation in the kinds of galaxies, the kinds of stars (and there is), then appropriate conditions to sustain life should be found somewhere, even if the probability for these conditions is small. That such conditions exist is then not in itself

remarkable, unlike the cosmological and physics conditions mentioned above and the chemical and biochemical ones below. Nevertheless, I'll mention some of them just to keep the catalog more or less complete.

4.2 "JUST RIGHT" GOLDILOCKS ZONES FOR PLANETARY SYSTEMS

Besides heat and light, stars emit "hard" radiation, ultra-violet, x-rays and gamma rays



Our Solar System's (Earth's) Location in Our Galaxy in an Outer Arm (the Orion Spur) from Wikimedia Commons

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such radiation the chemistry necessary for life could not take place. Earth is shielded from this hard radiation

from the sun by its atmosphere, including the ozone layer. Were there lots of other stars near the eart

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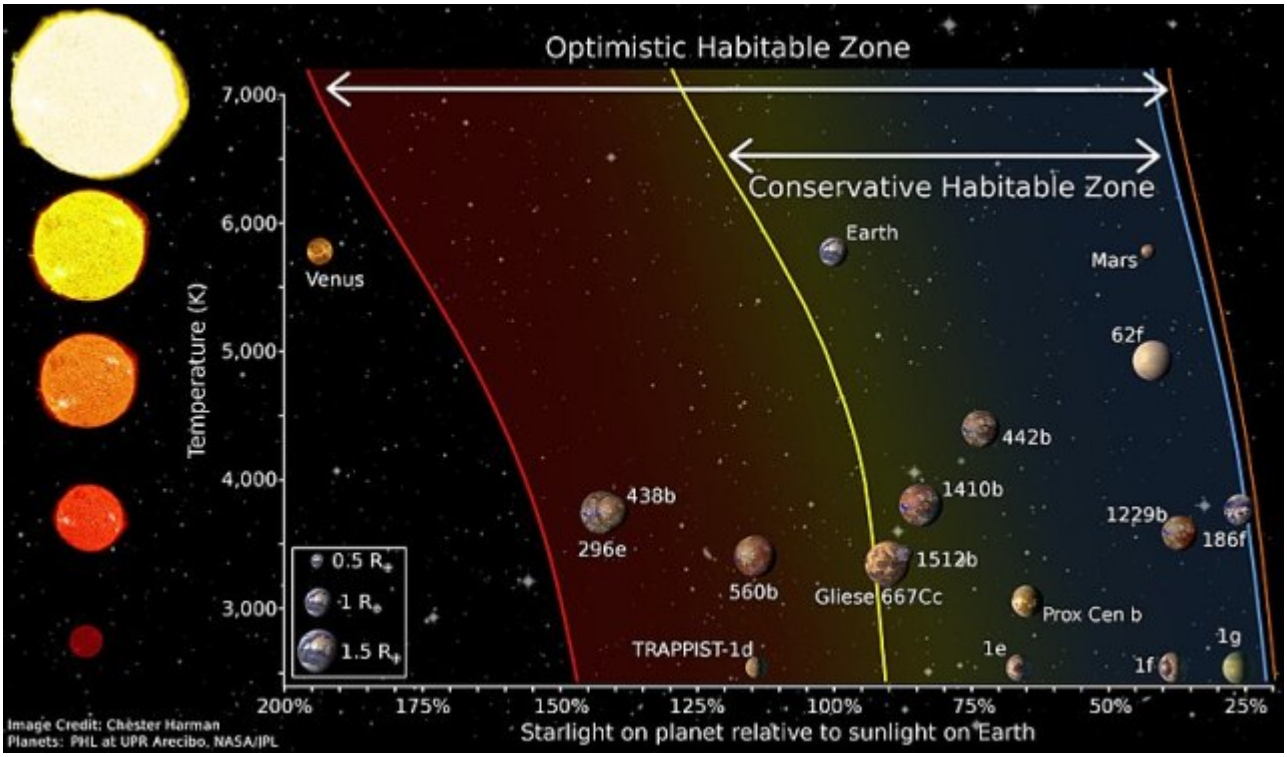
One other point should be noted. In multiple star systems with stars that are close together, the orbit of a planet for such a system would be highly eccentric, like that of a comet. Such an orbit would not be suitable temperature-wise for life: part of it would be too cold, part too hot (see below).

4.3 "JUST RIGHT" GOLDILOCKS ZONES FOR PLANETS"



Different Habitable Zones (Goldilocks Zones) by Sonny Harman (PSU)
from [Wikimedia Commons]

In order for life based on carbon chemistry to exist, there are conditions on its habitat. First, for chemical reactions to occur at a reasonable rate and for biological molecules to be stable, the temperature of the environment has to lie within a relatively narrow range. (Think of life on earth: it exists in the Antarctic and on the Death Valley desert, but that temperature range is still narrow in the cosmic scheme of things.) This required temperature imposes, in turn, a condition on the orbit of planets that might contain life: if the planet circles a relatively cold red dwarf, it will have to be much closer to that star than would a planet circling a hot blue giant.

A number of planets have been detected (not observed directly) by their gravitational effect on the star they orbit and by their effect on the star's radiation as they pass across it. An

extensive list of these is given here. Most of those listed are less than 50 light years away from our solar system. A few, detected by the Kepler space telescope, are several thousand light years distant. A diagram showing how this varies with type of star and distance from the star has been compiled by Sonny Harman (PSU)—see illustration above.

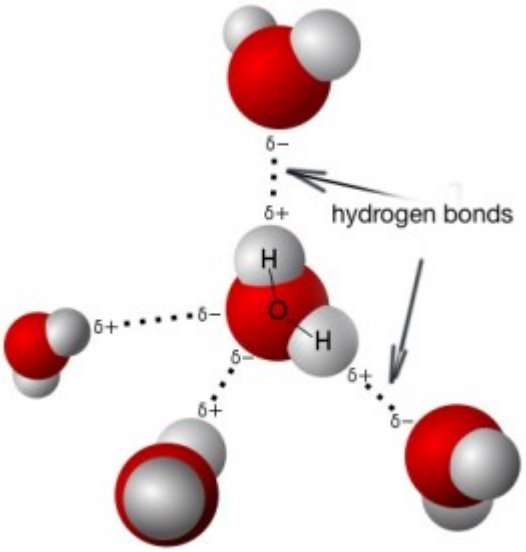
As noted below, much more is required for a life-friendly environment than a Goldilocks zone orbit for a planet.

4.4 EARTH'S "JUST RIGHT" UNUSUALLY LARGE MOON

Large planets (Jupiter, Saturn, Neptune) have large moons; small planets (Mars, Pluto) have small moons or none (Venus, Mercury). How the earth acquired its large moon is still something of a scientific mystery. But whatever the cause, our moon serves several purposes friendly for chemistry and life. It is a semi-shield, diverting meteors and larger bodies from the earth; it produces tides that moderate climate change. It alters the earth's orbit and polar inclination in a life-friendly way. Whether these purported effects are essential or just icing-on-the-cake of anthropic coincidences is a matter for debate, a debate in which I don't choose to engage.

4.5 "JUST RIGHT" PROPERTIES OF WATER FOR OUR EARTH.

There is a link between the physical properties of water and the planetary characteristics of earth—the tilt of its axis, the period of rotation,…—that give climactic conditions favorable to life. I've discussed these in a post, "The Theology of Water," which I'll summarize here. (More anthropic properties of water are discussed below in the context of chemistry and biochemistry.) These "just right" properties of water stem from one bit of chemistry, the hydrogen bond between hydrogen atoms on one water molecule and oxygen atoms on another, as shown in the illustration on the right The hydrogen bond is discussed in greater detail below, but the point to emphasize here is that it's a "just right" connection, not too strong and not too weak, a zipper, not glue or a na



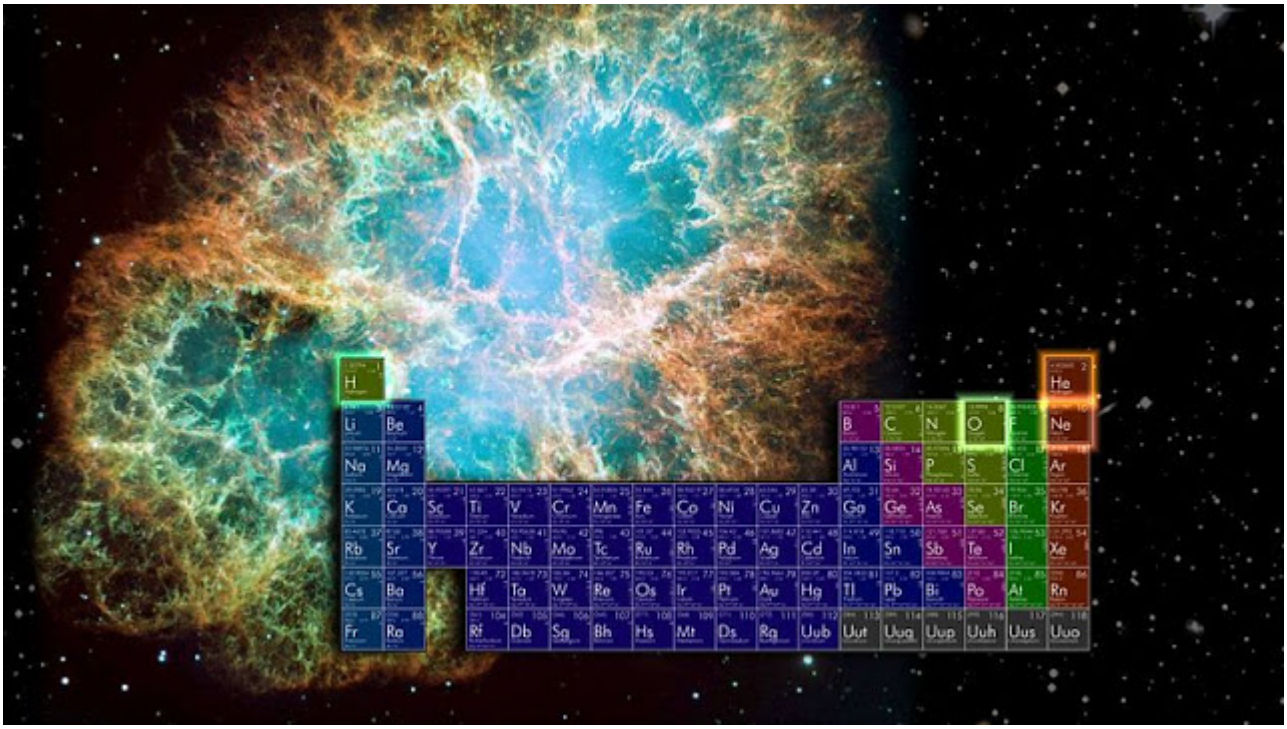
Hydrogen Bonds in H2O
d+, d- represent small electrical charge on H and O atoms, resp.
from Wikimedia Commons

liquid water has a maximum density at 4 degrees. If it didn't (if the maximum density was at the freezing temperature), the cold water would sink to the bottom of the ocean and earth's average surface temperature would be more than 20 degrees lower;
if the vapor pressure or the unusually high heat of vaporization of water is changed, either too much or not enough cloud would exist, which, in either case, would be a meteorological disaster;
if the density of ice is greater than that of liquid water at the freezing point (for most substances the density of the solid is greater than that of the melt), the ice would sink to the bottom of the oceans and the oceans would be perpetually frozen at the bottom, leading to massive winds at the surface;
if the high specific heat of liquid water is reduced, the temperature stabilizing effect of the ocean is lowered, and more storms and lower average temperature results;
the properties of water are optimized for the tilt of the earth's axis (23.5 degrees from the

vertical)–if it were 0 degrees tilt, the temperature stabilizing effect would be too large, with complete cloud cover and ice-caps down to 40 degrees latitude

The tilt of the earth's axis is responsible for seasons. When the polar regions are pointed to the sun during the polar summer, they become warmer so clouds tend to dissipate. Were there no tilt of the earth's axis and no polar summer, the polar regions and below would remain cool, and clouds would accumulate. Thus these regions would be further shielded from solar heat and would become colder still. There is a feedback principle involved.

SECTION 5: "JUST RIGHT' CHEMISTRY—HOORAY FOR GOD'S PERIODIC TABLE!



Periodic Table of the Elements superposed on the Crab Nebula (from a Supernova). From Wikimedia Commons

5.1 WHAT IS LIFE?

That's a question that philosophers and scientists have been arguing about for ages. It's also a question we should address before discussing what is required of chemistry, that life be enabled. So, here goes, a short list of just a few essential properties of living things:

Metabolism: living things takes matter and energy from the environment to sustain themselves;
Reproduction: living things beget, asexually or sexually, to yield descendants;
Growth: living things change form during their existence.

5.2 THE "JUST RIGHT" PROPERTIES OF CHEMISTRY.

Before proceeding further, I want to acknowledge that this will be a very sketchy discussion. To be complete a book or two on biochemistry, molecular biology and physiology would be needed. A more complete exposition of the chemistry and biochemistry background is given in the "Science Background" section of this Web-book. In this Essay I focus on hydrogen-bonding, that weak bonding is an essential property of water and biologically important molecules.

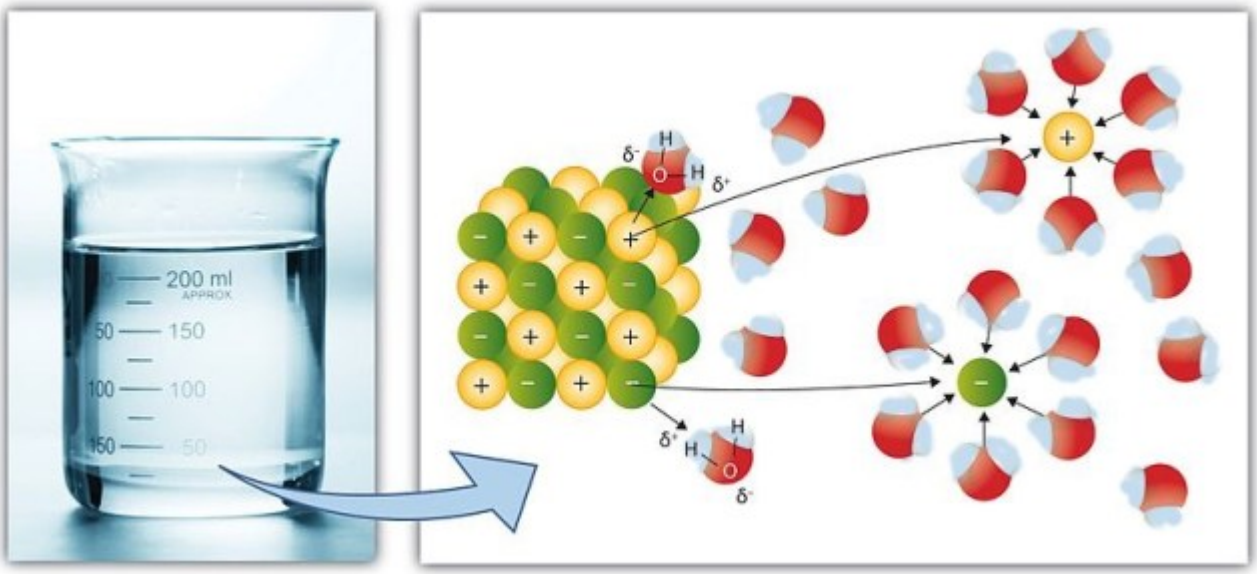
Here are two very general chemical properties that are required to enable living things that metabolize, reproduce, and grow:

Complexity, to enable living things to carry out many different biological functions; to transmit information within the organism and to descendants;
"*Just Right" Chemical Stability.* If biologically important molecules are too stable, metabolism and reproduction will be impossible—species will be inert and necessary chemical reactions won't occur; if molecules are too reactive, then they won't be in existence long enough to carry out required chemical functions

5.3 THE "JUST RIGHT" SOLVENT, WATER

> .*“The water that I shall give him will become in him a fountain of living water, welling up into eternal life. This is a new kind of water, a living, leaping water, welling up for those who are worthy. But why did Christ call the grace of the Spirit water? Because all things are dependent on water; plants and animals have their origin in water. Water comes down from heaven as rain, and although it is always the same in itself, it produces many different effects, one in the palm tree, another in the vine, and so on throughout the whole of creation. It does not come down, now as one thing, now as another, but while remaining essentially the same, it adapts itself to the needs of every creature that receives it.”*
>
> Quoted in the “Office of Readings” (Monday, Week 7 of Easter),from a catechetical instruction by St. Cyril of Jerusalem.

Water is called the “universal solvent” because it dissolves many kinds of molecules, enabling a variety of chemical reactions to occur. One property of water that aids solubility is hydrogen bonding, discussed below. Another is the ability to form loosely bound complexes of water with the components of salts, positive and negative ions, as shown in the illustration below for dissolving salt, NaCl:



Sodium Chloride (NaCl, salt) dissolving in water (H2O); yellow balls represent Na+ ions with unit positive charge; green balls, Cl- ions with unit negative charge; blue spheres, Hydrogen (H) in H2O; red spheres, oxygen (O) in H2O. Note the small positive charge, d+ on the H atoms in H2O and the small negative charge, d- , on the O atoms. from Wiklmedia Commons.

In the diagram above the slightly negative charged oxygen part of H2O is attracted to the positively charged sodium ion, Na+; the slightly positively charged hydrogen part of H2O is attracted to the negatively charged chloride ion, Cl-. Loosely bound complexes of Na+ ion and water molecules and Cl- ion and water molecules are formed to be in solution. The illustration is diagrammatic; sizes of ions and atoms are not to scale. The same type of solvation process applies for many other salts, compounds of potassium, calcium and other metal ions that have roles in biochemistry.

5.4 THE "JUST RIGHT" BOND STRENGTH OF THE HYDROGEN BOND: A ZIPPER, NOT GLUE

> *It has been recognized that hydrogen bonds restrain protein molecules to their native configurations, and I believe that as the methods of structural chemistry are further applied to physiological problems it will be found that the significance of the hydrogen bond for physiology is greater than that of any other single structural feature.*
> –Linus Pauling, "The Nature of the Chemical Bond"

Let's imagine God thinking about how He will design nature:

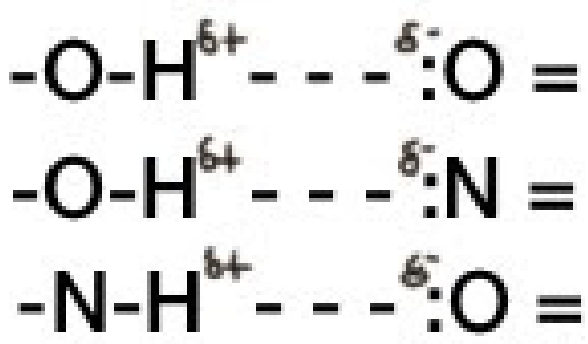
> *"Now I want chemistry to have not only strong interactions between atoms, but also gentle ones: so that complicated structures can unfold and rewind easily, and so that big and small molecules can come together and join for reactions and go apart readily–Velcro or a zipper, not glue or nails. What should I use? I have it–a hydrogen bond."*

(Note: please don't criticize me for heresy here–I'm using a semi-literary device to make a point. I know God holds an infinite number of thoughts and plans simultaneously in His infinite mind.)

Here's the basic idea: H (hydrogen) bonded to O (oxygen) as in H-O-H (water) shows a slight positive electrical charge; :O, oxygen, with a pair of unbonded (lone) electrons (the two dots in front of the O), shows a slight negative charge. Similarly, :N (nitrogen), with a pair of lone electrons, shows a slight negative charge, and N-H, hydrogen bonded to nitrogen, show a slight positive charge. There is an electrical attraction between these small positive and negative charges; there is also, as nmr experiments have recently shown, a contribution from chemical bonding (sharing of electrons) to hydrogen bonding, so that it is more than simple electrostatic interaction.

In the figure below are shown the types of hydrogen bonds important in molecules of

biological interest.



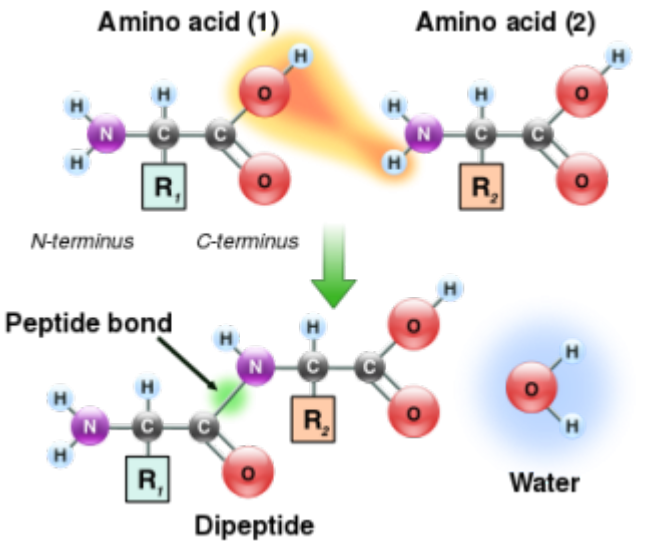
The single dashes represent single bonds;
The = signs, double bonds;
The – – -, hydrogen bonds;
The ” : “, lone pair electrons;
Superscripts, delta plus and delta minus, represent small net positive and negative charges.

Hydrogen bonds energies are about 1/20 to 1/30 the value of ordinary covalent bonds, so the hydrogen bonds can be broken much more easily than covalent bonds; for example the O-H bond energy is about 430 kJoules/mole, whereas the O-H – – – :O hydrogen bond energy is 21 kJoules / mole.

I’ll summarize the role hydrogen bonds play in biochemistry and molecular biology below. A more extended lesson on basic chemistry is given in the “Science Background” section.

5.5 “JUST RIGHT” BUILDING BLOCKS FOR PROTEINS, AMINO ACIDS

There are 20 amino acids that are the building blocks for proteins. Each amino acid molecule has a COOH, acidic carboxyl group (releases protons in solution), a NH2, basic amine group (accepts protons from solution) attached to a central carbon. Also attached to that group are 20 other different chemical parts, symbolized by “R”, as in the diagram at the right.



Amino Acid Structure; Peptide Formation (Two Amino Acids Combine) with Release of a H2O Molecule.
From Wikipedia.

The 20 amino acids that combine to build proteins are shown here. Proteins perform several essential functions:

catalysis, to speed up biochemical reactions (as enzymes);
transport of smaller species through the organism and through cells (for example, hemoglobin transporting oxygen);
building material for tissue;
engines to move tissue and muscle.
anti-bodies to remove unwanted and dangerous stuff

In all these functions parts of the proteins bind loosely to other parts of the protein and thus form appropriate structures that are essential to their function. This is shown very nicely in the TED YouTube video below, by Professor Ken Dill (SUNY/Stony Brook).

Another nice YouTube video showing protein flexibility is here. I should emphasize again that the flexibility and ability to form different structures is enabled by hydrogen bonds, bonds that can be zipped and unzipped readily, not glued or nailed. The diagram below illustrates how protein structures change when they act as a catalyst, that is as an enzyme:

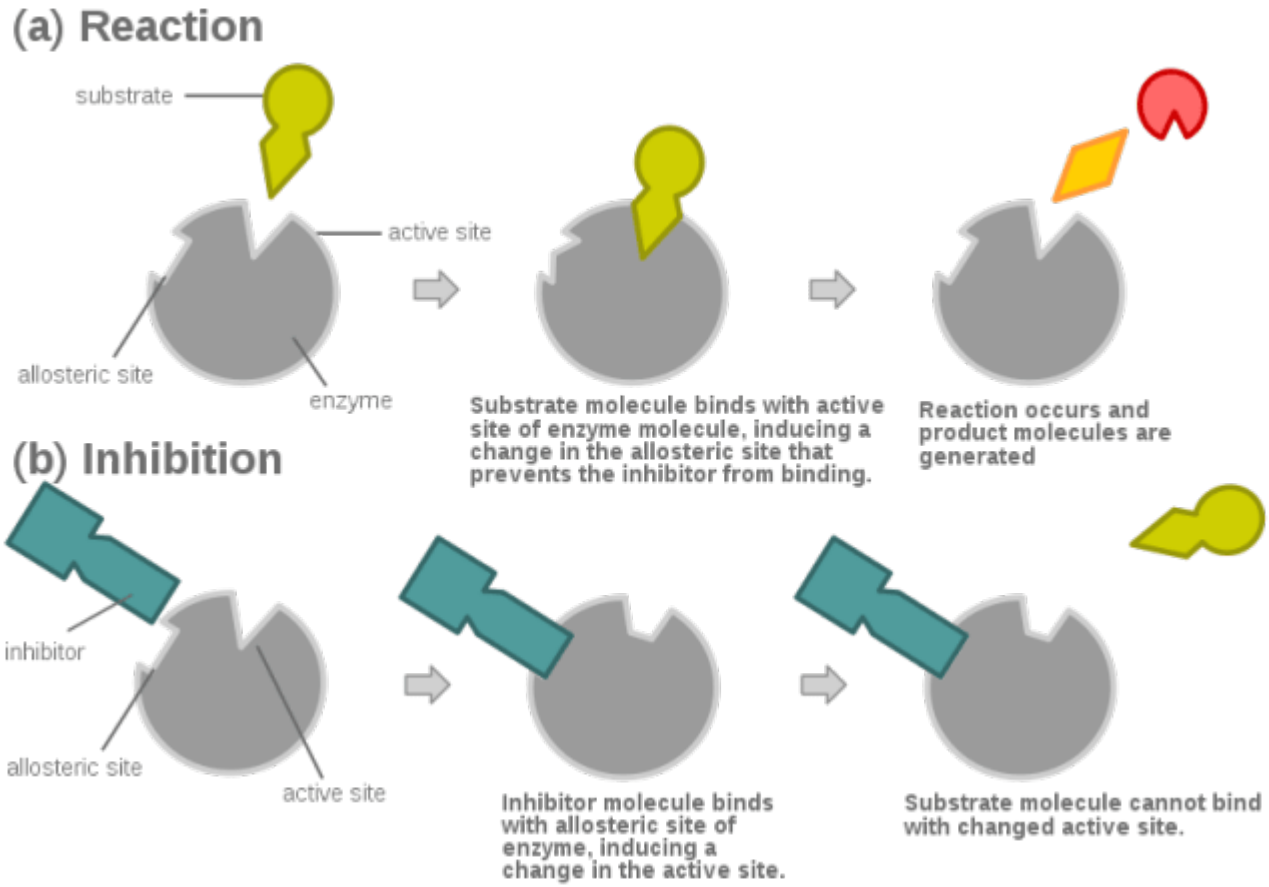
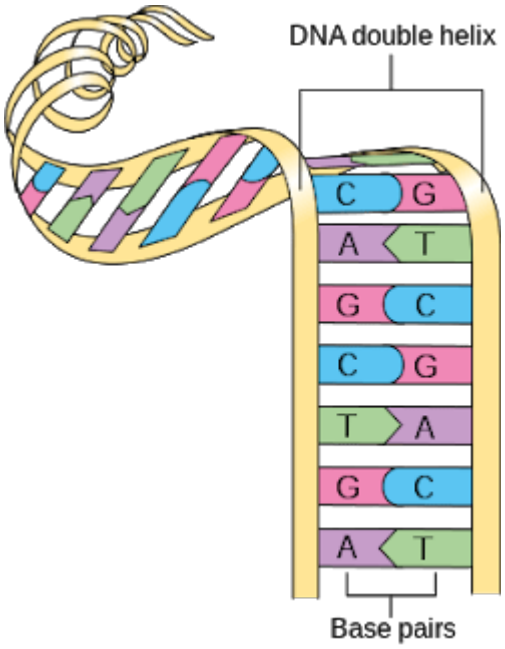


Diagram illustrating how protein structure changes to facilitate chemical reactions. from Wikimedia Commons

5.6 "JUST RIGHT" HYDROGEN BONDING FOR BASE PAIRING IN DNA

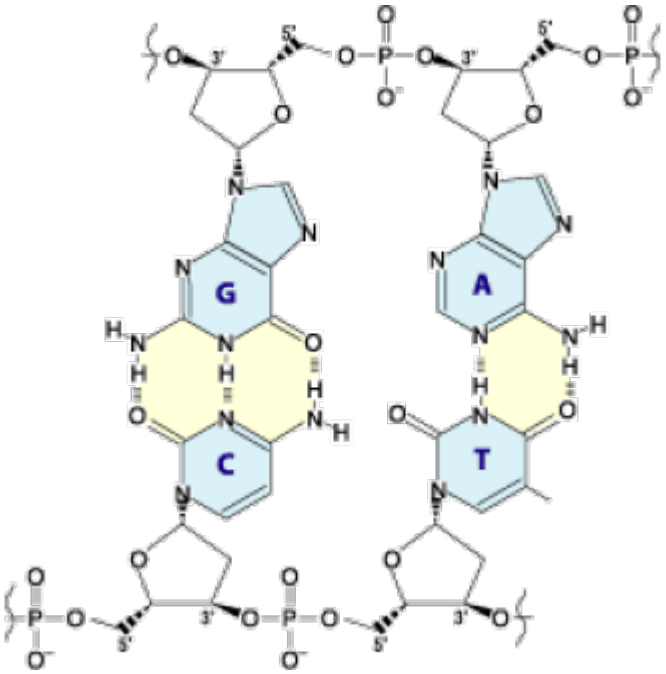
Watson (or was it Crick?) in a moment of insight noticed that the bases (nitrogen containing molecules bound to sugar pieces in nucleotides such as DNA, RNA) matched each other by hydrogen bonding like pieces in a jig-saw puzzle. They could thus stabilize a helical structure, by links across the spiral, as shown in the figure at the right..



Base pairing (diagrammatically) in DNA; letters stand for the bases shown below.
from Wikimedia Commons

There are four bases, adenine (A), cytosine (C), guanine (G), thymine (T), organic compounds containing a nitrogen or amine group that can take on proteins. Hydrogen bonds are formed to link the members of a pair, as shown below.

These bases are attached to sugar-type pieces, which in turn have phosphate groups on them that form the links between base units. The hydrogen bonds linking base pairs are strong enough to hold together the two DNA strands in the spiral helix, but weak enough that they can be “unzipped” by mild chemical action, an enzyme RNA polymerase, which yields messenger RNA.



Base Pairs:
Guanine (G) with Cytosine (C);
Adenine (A) with Thymine (T);
from Wikimedia Commons

5.7 ALPHABET BLOCKS TO CODE FOR BUILDING PROTEINS

Before discussing the mechanism by which DNA enables protein synthesis, a few remarks are in order about the bases as letters in a word, words which encode which amino acids are used as building blocks in the protein. In this process a linear combination of three bases is used to encode which amino acid is put into a protein. So we can regard the bases as letters and the combination of three bases as a three letter word; the three letter word is called a "codon". There are four bases* so there are 4^3 = 64 possible codons. There are 20 amino acids found in proteins, plus codons for beginning and ending protein synthesis, so that several codons may encode for incorporating the same amino acid, i.e. there is a redundancy. See here and here for tables showing specific codon / amino acid relations.

5.8 GENE EXPRESSION–TRANSCRIPTION AND TRANSLATION

I'll give just a brief summary here of gene expression–transcription and translation. More detailed accounts are given in the linked web sites and videos.

STEP 1: **transcription**–RNA polymerase unzips the double strand and attaches complementary bases to single strand RNA. See here and here. Note that the RNA polymerase is a large protein, much bigger than the DNA strand. Also note that one strand of the DNA serves as a "template"–bases complementary to bases in the template strand are linked, e.g. G to C, C to G, A to T, U to A, and as they're linked they detach to yield mRNA (messenger RNA). See the flash animation for a more detailed description of this process. PLEASE SEE THE LINKED ANIMATIONS–They will be well worth your while.

STEP 2: **translation-**-mRNA leaves the cell nucleus, goes into the cytoplasmwhere it attaches to a ribosome, where protein synthesis occurs. In the process transfer RNA molecules are sent by the ribosome to attach specific amino acids, coded by the m-RNA, to form a protein.

5.7 COMMENTARY

The description above is necessarily concise–a lot is left out and I urge the reader to look at the recommended links, animations and explanations and to explore this fascinating subject. Summarizing gene expression in one paragraph is much like trying to do that for the Bible, Old and New Testaments.

What amazes me is that molecular biologists and those who deal with gene expression, and all the other wonders of molecular biology don't paraphrase Psalm 19A: "DNA declares the glory of God, and gene expression shows forth the work of His hands..". Certainly the

hydrogen bond, which is a crucial element in these processes, neither too weak nor too strong, is a marvel in itself.
God's providence in molecular biology is as marvelous as it is in physics.

SECTION 6: Is there a Probability for the Universe?

"But is it probable that probability brings certainty?"
— Blaise Pascal,Pensees 496

6.1 THE 10,000 DIALS, 10,000 MONKEYS ANALOGY—

As the account above of the anthropic coincidences should suggest, the presence of organic life in the universe (namely us) requires a series of unlikely happenings and restricted values for physical laws and constants.

Can 50,000 monkeys typing randomly at a typewriter eventually produce Hamlet?
image from Wikimedia Commons

This “fine-tuning” (as it’s been called) has been likened to a room full of 10,000 dials, each of which has to be set to a precise setting in order to achieve action; 10,000 monkeys are let into the room and each adjusts a dial and, lo, action occurs.

In assessing the improbable nature of the anthropic coincidences, some authors assign a specific probability to the value of some particular physical constant. Such assignment is not always justified, because probability considerations are ill defined, in the usual sense of evidential probability.

For example, theoretical calculations have shown that if the strong nuclear force were 2 % higher or 2 % lower, then the elements as we know them would not have been formed. This does not mean that the probability of having the strong nuclear force at an anthropic value is 4%. In order to give a probability for this range, much more would have to be known about

how the physics of the strong nuclear force.

6.2 ERRORS IN PROBABILITY ARGUMENTS

A major objection to using such probability arguments, as Ellis points out above, is that the universe is a single datum—probability arguments are generally applied to samples from larger collections for which we have information about variability. For example, if you've examined 20,000 crates of oranges and found 100 crates containing bad oranges, you'd be justified in putting a probability of 100/20,000 or .005 in finding a bad orange in the next crate. But if you've only come across one crate of oranges, then it's speculation to put a probability on finding a bad orange.

Another error in probability arguments for the anthropic principle is to list a string of fine tuning examples (call them a,b,c,d…x), and then use the argument that P(a,b,c,d…x) = P(a) P(b) P(c)P(d)…P(x). This would say that the probability of the total set is the product of the probabilities for each member of the set. If the individual events were independent, in other words if what happened for one event did not depend on what happened for another, this argument would be correct. However, such independence will not necessarily hold. Consider, for example, the properties of water that are life friendly:

Thermodynamic—high freezing and boiling points, high specific heat, etc.;
Physical—surface tension, low specific gravity of ice, maximum density of liquid water at 4 deg C.

These properties all depend on the very unusual capacity of protons in a H2O molecule to form strong hydrogen bonds to oxygen atoms in other H2O molecules. That hydrogen bonding capability arises from quantum mechanics and the physical nature of electrostatic attraction. So it is one feature, not many, for which a probability should entered. Now, how do you assess the probability of quantum mechanics bringing about hydrogen-bonding?

Moreover, there is a difficulty in using probability in an after-the-fact, rather than a predictive sense. The way to use probabilities in assessing the anthropic coincidences is by Bayesian probability techniques, with well-defined prior assumptions, and to use the resulting Bayesian probability as a measure of belief. Such a procedure is discussed in one of my blog posts, "Is there a Probability for the Universe?"

NOTES

[1]This ratio is a very small number: about 1/10^36. Yes, that is 10 to the 36th power!

[2]Related to the requirement for 3 space dimensions and one time dimension, is the following: if there had been four space dimensions, then Gauss's Divergence Theorem would require inverse cube laws for gravitational and electrical forces, and motions under these would be very unstable.

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