Homework set #1 (assigned 10 September, due 19 September)

Instructions. These homework questions have many parts to them. Make sure you read the entire question and answer each and every part! You do not get any credit for problems or parts of problems that you do not attempt. Please consult the course syllabus for general instructions on working together: I encourage you think, work, and discuss together, but you should *write your homework assignments individually, not together*. Your homeworks do not have to be typed/computered, although of course that is fine. While I don't technically "count off" for spelling, grammar, and punctuation, mistakes of that sort do annoy me, and intelligibility does matter. You should also use sentences and paragraphs that explain your answers, not just one word answers. You should make sure that in all case your units agree. That is, if you are using meters, seconds, and grams for your calculations, make sure you don't accidentally have any kilometers, years, or kilograms (or, heaven forbid, pounds) in your calculations or solutions. For these reasons and oh-so-many-others, please proofread your homeworks before you turn them in. **Homework is due at the beginning of class on the designated due date**. I strongly suggest that you start looking over this homework assignment early – don't wait until the night before.

1) The bulk composition of the Earth is shown in Table 1. Compare this bulk composition to the cosmic abundance of elements at the formation of the Solar System. What elements are relatively enhanced in the Earth? What elements are relatively depleted in the Earth? Why do you think this is?

Jupiter's bulk composition is also shown in Table 1. Again, how does this bulk composition compare to the Solar System's composition (cosmic abundances) at its formation? Which elements are relatively enhanced and/or depleted, and why? How is Jupiter's bulk composition different from that of Earth's (in relative terms), and why? Hint: What do you know about Jupiter?

The composition of the Earth's lithosphere – the upper 10–30 km of the Earth – is also shown in the table. How does the bulk composition of the lithosphere compare to that of the bulk Earth, and to the Solar System's formation composition? What could explain these differences?

The composition of Earth's biosphere is also shown in the table. Again, how does this composition compare to Earth's lithosphere, the bulk Earth, and the pre-Solar System cosmic abundances, and why? What implications does this have for the search for life in the Universe?

2) The nearest star to the Earth is Proxima Centauri, about 4.2 light years distant (4.2 light years = 4×10^{13} km = 1.3 parsecs). A typical very nearby star might be 20 parsecs distant. Escape velocity for our Solar System – that is, the velocity that a comet/asteroid/spaceship must have in order to leave our Solar System – is something like 600 km/sec. What is the travel time, assuming escape velocity, between a typical very nearby star and the Earth? Your answer should be in years.

Life is thought to have originated very early on Earth, probably as early as 3.8 billion years ago (recall that the age of the Earth is around 4.5 billion years). A particularly violent period of the Earth's history called Late Heavy Bombardment (we will talk about this later in the course) ended around 3.9 billion years ago. One criticism/concern about the origin of life on Earth is that perhaps that 100 million years wouldn't be enough time for life to originate here on Earth. The counter-proposal is that life could have originated elsewhere in the Universe and traveled to Earth.

Using the travel time you calculated above, does this proposed solution help at all?

The galaxy is around 100 kiloparsecs across (1 kiloparsec = 1000 parsecs). Assuming life originated around a Sun-like star, from how far across the galaxy could a panspermic life-form travel to the Earth if the oldest Sun-like star in the galaxy is around 10 billion years old? How much time could you allow for life to originate if it originated at the birth of a 10 billion year old star on the opposite side of the galaxy?

The typical density of very nearby Sun-like stars might be around 0.01 Sun-like stars per cubic parsec (think of a volume in space; the volume of a sphere is equal to $\frac{4}{3}\pi r^3$ where r is the radius of the sphere). How many Sun-like stars are there within the typical very nearby volume (of, say, radius 20 pc)? How about in the whole galaxy (assuming that the space density of Sun-like stars is constant throughout, which it almost certainly isn't)? You can assume the galaxy is a sphere (which, again, it isn't). If life had to originate around one of these Sun-like stars in order to travel panspermically to the early Earth, how many eligible Sun-like stars are there from which life could have begun its travels?

Now imagine that you are riding along on a panspermically-rich comet or asteroid that has made its way from another planetary system to our Solar System. You start to approach our Solar System (radius around 50 AU, where 1 AU is 1 Astronomical Unit, which is equal to 1.5×10^8 km); imagine that you have a "top-down" view, where you are looking down on the planets orbiting around the Sun. What is the probability that out of the entire Solar System's area (as seen from your perspective), you will land on Earth? (The planetary radius of Earth is around 6700 km.) It will certainly help you to figure out this problem if you *draw a picture.*

Lastly, how likely do you think this all is? By all, I mean all of the steps you have considered above here. You can calculate this numerically but you do not have to – you can answer in words/thoughts/gut feelings instead.

3) This question will help you think about information and biomolecules. How many nucleic acid bases are there in RNA? How many different combinations of these bases could you create if you had a protein polymer strand that was four bases long? How about if your strand was 8 bases long? or 80? You can see that the complexities of life can be stored in genes – you just need to make genes big enough and you can store arbitrarily large amounts of information in them. Information here simply means what kind of base you have in a given order, position, or sequence. How many pieces of information can be carried on a single human gene? Compare this to how many physical "characteristics" a human being has.

Now think about proteins. Proteins are made of amino acids, and life on this planet uses 20 different amino acids. How many different proteins could you make if you had a polymer which was 4 amino acids long? How about 8, and 80? So – you can see that, although protein polymers are made up of many fewer monomers than RNA polymers are, there is still an enormous amount of complexity available for proteins. That explains (in part) why proteins are so flexible and valuable and have such a wide range of tasks in living systems.

4) Do some research – yes, web research is okay – to figure out the bulk compositions of the following things: a human being; a computer; a tree; a block of granite; a dog; a bacterium; a car; and a book. Discuss how CHON relates to your answers. You may have to do some estimating, creative thinking, or guessing – that's okay! Just make sure that you justify all your answers/assumptions.

Note about doing research and web research especially: you must – absolutely must – note, credit, and cite all of the resources you use. You absolutely may not write down that books are made of plastic and refer to "the web." You must cite specific web pages the same way you would cite specific books – and don't forget, it really is okay to do this research in the traditional library using traditional books. I encourage you to be somewhat skeptical of web sources – after all, any idiot can post anything s/he wants on a web page, and I might find it and believe it. See if you can find two or three sources which seem to say the same thing before you believe the answer.

5) Describe why, using terms like valence, ionic bond, covalent bond and also other things you have learned in the class so far, CH_4 (methane), NH_3 (ammonia), and CO_2 (carbon dioxide) were probably common molecules in the early Solar System but NH_4 (ammonium), SiO_2 (silicon dioxide, which is quartz), NaCl (sodium chloride, which is salt), and CO (carbon monoxide) might have been less common in the early Solar System.

6) The early Earth was a hot place. In addition to the many impacts of asteroids and comets and also in addition to volcanos, radioactive decay may have played a role in heating the early Earth. ^{26}Al is a radioactive isotope that decays to ^{26}Mg with a half-life of 720,000 years. Each atom of ^{26}Al that decays gives off 2.9×10^{-13} J (a Joule is the metric unit of energy).

When aluminum is created inside stars (and supernovas), the fraction of all aluminum that is ^{26}Al is around 5×10^{-5}. How much heat (energy) was created in the first 1.5 million years of the Earth's existence through radioactive decay of ^{26}Al? For the purposes of this problem, you may assume that the Earth's age started when it was fully formed, that is, no decay happened before the Earth reached its final mass of 6×10^{27} g. You also might want to know that there are 6×10^{23} atoms of Al in one gram of Al.

This amount of heat energy might not be that intuitive to you, so let's compare to something you do know about. *Power* is the amount of energy expended (or produced) over time. The metric unit of power is the Watt, and 1 W is equal to 1 Joule per second. How much power was produced from the ^{26}Al in the early Earth? How does this power compare to a common household appliance? How does it compare to the power output of the Sun, which is about 3×10^{26} W?

Table 1: Approximate compositions (in percent by weight)

Element	Bulk Earth	Earth's lithosphere	Earth's biosphere	Bulk Jupiter
H	0.003	0.14	$<$1	86
He	$\sim$0	$\sim$0	0	14
C	$<$1	$\sim$10	$\sim$60	$<$1
N	$<$1	$\sim$8	$\sim$1	$<$1
O	30	46.6	$\sim$20	$<$1
Mg	14.9	2.1	0	0
Al	1.59	7.6	0	0
Si	14.9	27.7	0	0
S	1.9	$<$1	$<$1	$<$1
Fe	35	5.3	0	0
Other	5	$<$1	$<$1	$<$1