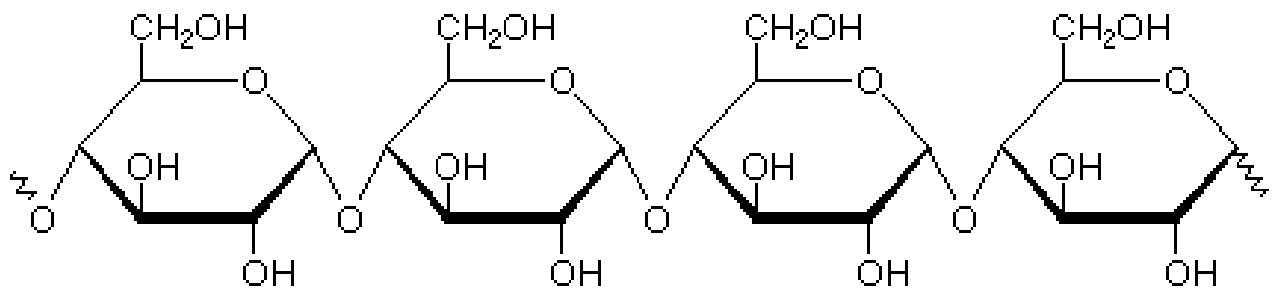


Work carefully, you'll have enough time. Give enough details, not just the numbers. when requested. For the multiple choice questions 1–56, there is only one correct/best answer! Mark it with a circle & enter it into the scantron.

1. Which of the following is not a key property of life? [2pts]
 - (a) The maintenance of order in living cells
 - (b) The ability to evolve over time
 - (c) **The ability to violate the second law of thermodynamics?**
2. Natural selection is [2pts]
 - (a) the occasional mutations that occur in DNA;
 - (b) **the mechanism by which advantageous traits are preferentially passed on from parents to offspring;**
 - (c) the idea that organisms can develop new characteristics during their lives and then pass these on to their offspring.
3. An enzyme is a molecule that [2pts]
 - (a) **speeds up a reaction, but is not itself chemically involved in it**
 - (b) speeds up a reaction, and is itself chemically involved in it
 - (c) enables a reaction that can otherwise only proceed in opposite direction
 - (d) provides mechanical support for the reaction partners to come into contact
4. What kind of macromolecule is [2pts]



- (a) lipid (b) **carbohydrate** (c) protein (d) nucleic acid

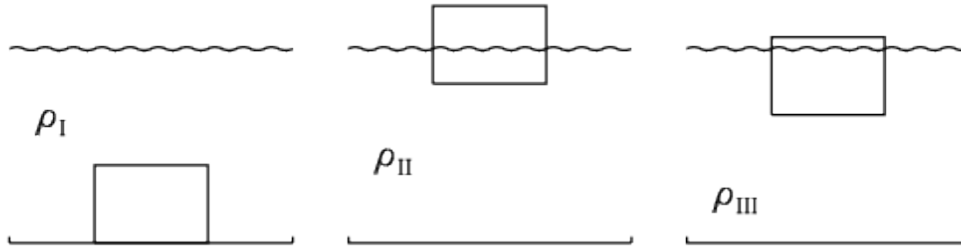
5. Which of these nucleobases is a component in DNA but not in RNA? [2pts]
 - (a) Uracil [U] (b) Cytosine [C] (c) Adenine [A] (d) **Thymine [T]** (e) Guanine [G]
6. Limestone belongs to which of the following three basic rock types: [2pts]
 - (a) igneous rock (b) metamorphic rock (c) **sedimentary rock**
7. In the icy bodies of the solar system, the crust consists mostly of [2pts]
 - (a) **water ice** (b) liquid water (c) water vapor (d) ammonia

8. Why are carbohydrates useful for organisms? [2pts]
- (a) they can store energy
 - (b) they have enzymatic properties
 - (c) they can act as information carrier
 - (d) they are an essential component of membranes
9. Every amino acid contains one of the following chemical groups [2pts]
- (a) the hydroxyl group ($-OH$)
 - (b) the methyl group ($-CH_3$)
 - (c) the amino group ($-NH_2$)
10. In the genetic code of contemporary life, each codon (or word) codes for [2pts]
- (a) a particular nucleotide
 - (b) a particular amino acid
 - (c) a short peptide
 - (d) a particular protein
11. Which of the following mutations has the most devastating effect? [2pts]
- (a) one that changes a single base in a region of non-coding DNA
 - (b) one that deletes one base in the middle of a gene
 - (c) one that changes the third letter
12. In the Universe, carbon is mainly being produced [2pts]
- (a) during the big bang
 - (b) during the late stages of stellar evolution
 - (c) during supernova explosions
 - (d) during neutron star mergers
13. Why are stars not alive? [2pts]
- (a) they don't grow
 - (b) they don't expel waste
 - (c) they don't consume energy
 - (d) they don't die and produce offspring
 - (e) their evolution is not subject to mutations
14. Which of the following monomers of building blocks were *not* found in the Murchison meteorite? [2pts]
- (a) amino acids
 - (b) sugars (monosaccharides, i.e., single sugars)
 - (c) nitrogenous bases (i.e., basepairs of nucleotides)
 - (d) lipids (hydrocarbons and acids)
 - (e) none (i.e., all are found)

15. The importance of the Miller/Urey experiment is that it [2pts]
- (a) proved beyond doubt that life could have arisen naturally on Earth
 - (b) showed that natural chemical reactions can produce building blocks for life
 - (c) showed that clay can catalyze the production of RNA
16. In the Miller/Urey experiment, [2pts]
- (a) all four nitrogenous bases can be synthesized
 - (b) all four building blocks of life can be synthesized
 - (c) amino acids are easily produced under reducing conditions
 - (d) all amino acids have left-handed chirality
17. What is panspermia [2pts]
- (a) a hypothetical life form before the RNA world
 - (b) the accidental contamination of a planet with terrestrial microbes
 - (c) the transfer of spores from one celestial body to another
 - (d) the ejection of meteorites from one planet to another
18. Metabolism requires [2pts]
- (a) a source of carbon
 - (b) a source of energy (i.e., electron donor)
 - (c) an oxidant (i.e., electron receptor)
 - (d) all of the above
19. The realization that much of Europa's subsurface water is in liquid form comes from [2pts]
- (a) measurements of its mean density
 - (b) measurements of magnetic field perturbations by Europa
 - (c) the detection of outgassing through the cracks
 - (d) theoretical calculations of the amount of tidal heating
20. The RNA world became popular after the discovery that RNA [2pts]
- (a) is less stable than DNA and can therefore mutate more easily
 - (b) contains the same RNA as LUCA, the last universal common ancestor
 - (c) can perform catalytic reactions without the need of producing proteins
 - (d) can be synthesized relatively easily under prebiotic conditions
 - (e) can contain more than just the usual four base pairs
21. Old fossilized stromatolites provide evidence [2pts]
- (a) for early photosynthetic life
 - (b) that life emerged first in the oceans
 - (c) that the first life must have been chemotrophic
 - (d) that the first life must have been photosynthetic

22. A planetary system with a big Jupiter-sized planet could increase the possibility of finding life on an inner terrestrial planet, because it [2pts]
- (a) prevents synchronous rotation on the inner planets
 - (b) helps reducing the rate of bombardment on the inner planets
 - (c) protects the inner planets from electrically charged particles
 - (d) facilitates panspermia on the inner planets
23. The dense core of an Earth-like planet is found to occupy 1/27 the volume of the planet – what fraction of the planet’s radius does the core occupy? [2pts]
- (a) 1/27 (b) 1/6 (c) 1/3 (d) 1/9
24. Marble is created when limestone is subducted beneath the surface and repeatedly folded over itself in the hot mantle (without melting). Knowing this, what kind of rock is marble? [2pts]
- (a) Sedimentary. (b) Metamorphic. (c) Igneous. (d) Marble is none of these types.
25. Which of these is not necessarily needed for terrestrial life to function? [2pts]
- (a) Free O₂ gas (b) Liquid water (c) A carbon source (d) Nitrogenous bases
26. Two powders, one yellow and one purple, are stirred into a beaker of water. The purple powder dissolves completely, but the yellow powder collects on the bottom. What can you reasonably state about the chemical nature of these powders? [2pts]
- (a) purple is polar; yellow is apolar
 - (b) neither powder is polar
 - (c) yellow is polar; purple is apolar
 - (d) both powders are apolar
27. The rocky mantle of the Earth contains radioactive potassium. Why is it important that Argon, one of the decay products, it is a gas? [2pts]
- (a) it is trapped in the Earth’s atmosphere, allowing us to estimate the age of the Earth
 - (b) it is trapped inside rocks, allowing their age to be determined after solidification
 - (c) it causes granite to be lighter than basalt, preventing it from being subducted
 - (d) it can readily be separated from the rock for the purpose of quantitative analysis
28. In which of these environments would you likely find a piezophile? [2pts]
- (a) A high-altitude desert
 - (b) An Amazon rain forest log
 - (c) A deep-sea vent
 - (d) A wall in the Chernobyl reactor

29. Three identical blocks of plastic are floated in three separate pools of liquid labelled I, II, and III. The block in pool I sinks, the block in pool II floats with 40% of its volume submerged, and the block in pool III floats with 90% of its volume submerged. How do the densities of the three liquids (ρ_I , ρ_{II} , and ρ_{III}) compare? [2pts]



- (a) $\rho_I < \rho_{II} = \rho_{III}$ (b) $\rho_{II} > \rho_{III} > \rho_I$ (c) $\rho_I > \rho_{III} > \rho_{II}$

30. In order for the Earth with its greenhouse gases to maintain a constant temperature, it [2pts]

- (a) must receive more energy from the Sun than it radiates into space
 (b) must receive the same amount of energy than what it radiates into space
 (c) must receive less energy than it radiates, because of its greenhouse gases

31. Which of the following extremophilic organisms have been found near the root of the phylogenetic tree of life? [2pts]

- (a) psychrophiles
 (b) thermophiles
 (c) piezophiles
 (d) radiophiles
 (e) xerophiles

32. The reaction $\text{CaSiO}_3 + \text{H}_2\text{CO}_3 \rightarrow \text{CaCO}_3 + \text{SiO}_2 + \text{H}_2\text{O}$ describes [2pts]

- (a) an autotrophic metabolic pathway
 (b) a heterotrophic metabolic pathway
 (c) the weathering of basalt into granite
 (d) the production of limestone by acidic rain
 (e) the onset of carbon burning during stellar evolution

33. Earth has far less atmospheric CO_2 than Venus because [2pts]

- (a) the Earth was born with less atmospheric gas to begin with
 (b) it lost its CO_2 during the moon-forming impact
 (c) the CO_2 is locked up in carbonate rocks
 (d) the CO_2 escaped into space

34. What has caused the banded iron formations in the old part of the geological record? [2pts]
- (a) the oxidation of ferrous iron (FeO) into insoluble ferric iron (Fe₂O₃)
 - (b) the process by which early autotrophs turned oxidized iron into rust
 - (c) the shortage of reduced iron as nutrients for phytoplankton
35. The emergence of oxygen in the atmosphere caused [2pts]
- (a) a global disaster for most life on Earth
 - (b) the migration of life from water to land
 - (c) the emergence of first planet life
36. The young Sun was [2pts]
- (a) fainter than now
 - (b) brighter than now
37. Which of the following rock types is *not* found on Mars? [2pts]
- (a) granite
 - (b) basalt
 - (c) limestone
 - (d) sandstone
 - (e) all of the above
38. Carbon-13 (¹³C) [2pts]
- (a) is radioactive and therefore not present in living organisms
 - (b) is enhanced in all biological carbon deposits compared with abiogenic carbonates
 - (c) is depleted in all biological carbon deposits compared with abiogenic carbonates
 - (d) can be used to infer the temperature on the Early earth
 - (e) accumulates over time in old rocks
39. What is a peptide? [2pts]
- (a) a single amino acid
 - (b) a short polymer of amino acids
 - (c) a protein
 - (d) an oxidized amino acid
 - (e) an achiral amino acid
40. Which of the following possible analogies between terrestrial and icy bodies of the solar system is not correct? [2pts]
- (a) Iron core (in terrestrial bodies) \iff rocky core (in icy bodies)
 - (b) Silicate mantle (in terrestrial bodies) \iff liquid water (in icy bodies)
 - (c) Rocky crust (in terrestrial bodies) \iff water ice (in icy bodies)
 - (d) Lava (in terrestrial bodies) \iff slush ice (in icy bodies)
 - (e) CO₂ (in terrestrial bodies) \iff SO₂ (in icy bodies)

41. What is the primary reason why Lake Vostok underneath 3 km of antarctic ice does not freeze? [2pts]
- (a) Because of high pressure
 - (b) Because of insulation by the ice
 - (c) Because of geothermal heat
 - (d) Because of a high salt content
 - (e) Because of tidal forcing
42. Why is there tidal heating of the moons of the giant gas planets? [2pts]
- (a) because of tidal locking of the moons to the planet
 - (b) because of the close proximity to the gas planet
 - (c) because of the tilt of the rotation axis of the moons
 - (d) because of the elliptic orbit of the moons
 - (e) because the water of the moons bulges
43. The search for Extraterrestrial Intelligence has traditionally been conducted at or around the 21 cm radio wavelength, because [2pts]
- (a) those waves penetrate dust and planetary atmospheres
 - (b) it is a key transition line for neutral hydrogen in the Galaxy
 - (c) any technically developed civilization would have sensitive receivers in that wavelength
 - (d) all of the above
44. The radius of an exoplanet can be determined with the [2pts]
- (a) radial velocity method
 - (b) transit method
 - (c) direct imaging
 - (d) gravitational lensing
 - (e) all of the above
45. Compared with the bodies in the solar system, the terrestrial planets around the 11.2 Gyr old star Kepler-444 are likely to [2pts]
- (a) have moved outside the habitable zone
 - (b) harbor ancient life
 - (c) have more oxygen
 - (d) have more iron
 - (e) have less iron
46. A star shade [2pts]
- (a) is a naturally occurring flower in space
 - (b) is a huge sail to visit Proxima Centauri b
 - (c) occults the light of the host star
 - (d) is a natural stellar eclipse
 - (e) a sunspot-like phenomenon, but on a star

47. Which of these objects is a planet? [2pts]
- (a) Proxima Centauri b
 - (b) α Centauri A
 - (c) α Centauri B
 - (d) Sirius A
 - (e) all of the above
48. Why is the *combined* presence of oxygen (or ozone) and methane in an exoplanet's atmosphere regarded as being a fairly conclusive indicator of life on that planet? [2pts]
- (a) Both molecules are necessary ingredients of life
 - (b) Both molecules are waste products of contemporary life
 - (c) These molecules react with each other and must constantly be supplied by life
 - (d) These two molecules together cannot be produced by abiogenic processes
49. In the Earth's atmosphere, ozone is being produced from oxygen mostly through [2pts]
- (a) lightning
 - (b) air planes
 - (c) forest fires
 - (d) UV radiation
 - (e) laser printers and Xerox machines
50. To communicate with terrestrials, intelligent martians could have [2pts]
- (a) send radio signals during opposition
 - (b) direct high-powered lasers to Earth
 - (c) use mirrors to shine light to Earth
 - (d) plant trees in a pattern
 - (e) all of the above
51. Life at the surface of terrestrial planets around M dwarfs is [2pts]
- (a) impossible because of synchronous rotation of the planet
 - (b) likely because the planets are closer to the host star
 - (c) not easy because of high levels of radiation
 - (d) harsh because of low temperatures
52. Starshot is an attempt to [2pts]
- (a) launch a massive space ship into interstellar space
 - (b) accelerate a space chip to close to speed of light
 - (c) communicate with people on Proxima Centauri b
 - (d) bring a colony of people to the next star
 - (e) install a huge solar sail on the moon

53. The gamma ray spectrometer was the first instrument orbiting Mars to discover subsurface water in frozen or liquid form. Where was most of it detected? [2pts]
- (a) at high latitudes
 - (b) at mid latitudes
 - (c) near the equator
54. Why do we think life didn't begin in the Earth's early oceans? [2pts]
- (a) Earth's early oceans were too hot for life to form.
 - (b) Nutrients in the ocean were too dispersed to be useful.
 - (c) Earth's early oceans were too acidic
 - (d) Early ocean water didn't contain dissolved carbon.
55. Select which of the following applications of artificial life are conceivable [2pts]
- (a) producing CO₂-neutral fuels
 - (b) cleaning up oil-spills & removing waste
 - (c) attacking cancer cells & other medical treatments
 - (d) engineering deadly organisms with no natural enemies
 - (e) all of the above
56. To avoid the dangers of deadly organisms spreading our planet, which of the following suggestions have been discussed as being particularly promising? [2pts]
- (a) develop a suitable "antivenom" against the bacterium
 - (b) develop life that cannot survive in the absence of oxygen
 - (c) engineer life that lives of unnaturally occurring ingredients
 - (d) engineer life whose genome is tagged with a trademark
 - (e) reduce the size of the genome to 500 kilo base pairs
57. In the reaction $\text{CO}_2 + 4\text{H}_2 \rightarrow \text{CH}_4 + 2\text{H}_2\text{O}$,
- the energy comes from: (sunlight/molecules), so the relevant prefix is (photo/chemo)
- the electron donor is:H₂....., which is (organic/inorganic), so (organo/litho),
- and the carbon source is:CO₂....., which is (organic/inorganic), so (hetero/auto),
- and so it is a:chemolithoauto....troph. [6pts]
58. In the reaction $2\text{O}_2 + \text{CH}_4 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O}$,
- the energy comes from: (sunlight/molecules), so the relevant prefix is (photo/chemo)
- the electron donor is:CH₄....., which is (organic/inorganic), so (organo/litho),
- and the carbon source is:CH₄....., which is (organic/inorganic), so (hetero/auto),
- and so it is a:chemoorganohetero....troph. [6pts]

59. An old genome is found to encode information using DNA very much like ours – however, this genome uses only two bases (C and G) rather than the usual four (A,T,C,G).

- (i) With a word length of 3 letters, how many possible amino acids could this alien genome uniquely encode for?

(Explain how you calculate this; don't write just numbers!) [2pts]

There are 3 slots to fill (each letter of the 3-letter word) and for each slot there are 2 choices (C or G), so we could code for $2 \times 2 \times 2 = 2^3 = 8$ possible amino acids.

- (ii) How does this change if each word has only 2 letters? *(Again, explain what you are doing!)* [2pts]

Now there are only 2 slots to fill (each letter of a 2-letter word), but for each slot there are still 2 choices (C or G), so we could code for $2 \times 2 = 2^2 = 4$ possible amino acids.

60. As Cassini flew over the “tiger stripes” on the surface of Enceladus, it recorded periodically enhanced levels of hydrogen. This is thought to be evidence of hydrothermal activity at the subsurface ocean floor of Enceladus. Explain this by writing a balanced equation to describe the oxidation of ferrous iron (FeO) with water to ferric iron (Fe₂O₃) and hydrogen. [4pts]



61. Name the three basic rock types and give an example for each of them. [6pts]

- Igneous rock — example basalt
- Metamorphic rock – example: marble
- sedimentary rock — example: limestone

62. Deep in the ocean, certain bacteria make their biological living by performing the following reaction



Determine what kind of -troph this bacterium would be. Justify each of the prefixes used in your answer. [6pts]

The energy comes from molecules, so it's a *chemo*.

The electron donor is H_2S , which is inorganic, so it's a *litho*.

The carbon source is CO_2 , which is inorganic, so it's an *auto*.

The organism is therefore a chemolithoautotroph.

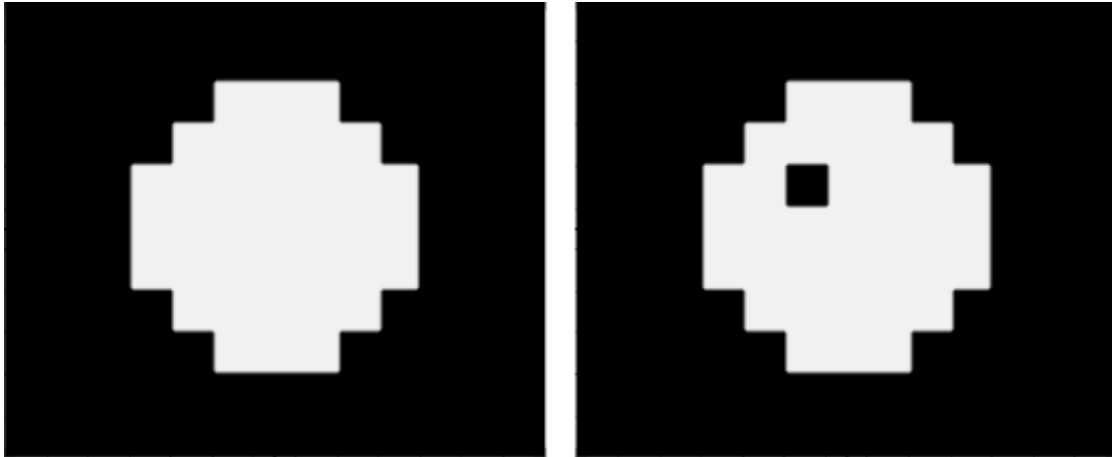
63. A sample of lunar rock has about the same amount of potassium-40 (^{40}K) and argon-40 (^{40}Ar). In order to determine the age of this rock sample, let us consider a sample of 16 mg of ^{40}K . Below is a partially completed table describing the decay of ^{40}K into ^{40}Ar . Complete the table, calculating how much potassium remains at each step and how much total argon has been accumulated. We are looking for when the argon and potassium levels are the same. So, at each step, check whether the amount of potassium is still more than that of argon until this is no longer the case. At the end you can say that the rock must be less than so-and-so many half-lives, but more than so-and-so many.

- Complete the table below, compare the numbers in the relevant columns (indicated by bold face numbers), and stop when you find "No" in the last column. [4pts]

time in half-lives	potassium (mass in mg)	decay products (in mg)	10% of it (in mg)	accumulated argon (in mg)	still more potassium than argon?
0	16	0	0	0	Yes
1	8	8	0.8	0.8	Yes
2	4	4	0.4	1.2	Yes
3	2	2	0.2	1.4	Yes
4	1	1	0.1	1.5	No
5					

- The age of the rock must be more than 3 half-lives but less than 4 half-lives. [2pts]
- Given that the half-life of ^{40}K is 1.25 Gyr, the age of the rock must be more than 3.75 Gyr but less than 5 Gyr. [2pts]

64. In the two figures below, you see a coarse-grained image of Proxima Centauri, but on the right a transit by Proxima Centauri b is in progress. Each white pixel emits at an intensity of 10^6 W.



- (a) What is the surface area of Proxima Centauri in pixels? [2pts]
 37 pixels
- (b) What is the surface area of the planet Proxima Centauri b in pixels? [2pts]
 1 pixels
- (c) What is the total intensity I of Proxima Centauri? [Again, use the number of pixels.] [2pts]
 37×10^6 W
- (d) During transit, the total intensity has dropped by an amount ΔI . What is this amount? [2pts]
 10^6 W
- (e) Assume that the radius of the planet is $r = 6,000$ km and the radius of the star is $R = 36,000$ km. Compute the square of the ratio $\frac{r}{R}$ and compare with $\frac{\Delta I}{I}$. [2pts]
 $\left(\frac{r}{R}\right)^2 = \left(\frac{6}{36}\right)^2 = \left(\frac{1}{6}\right)^2 = \frac{1}{36}$, which is just slightly larger than $\frac{\Delta I}{I} = \frac{1}{37}$.

65. Drake's equation gives the number N of civilizations broadcasting their existence in our galaxy. In its simplest form this equation depends only on the rate R_b at which new broadcasting civilizations emerge and on the length of time t over which each civilization broadcasts

(a) Write down Drake's equation in its simplest form [2pts]

$$N = R_b t$$

(b) What is the *most conservative* estimate for N ? [2pts]

$$N=1$$

(c) Justify your answer (think of an example) [2pts]

This is us, i.e., the civilization on Earth

(d) Assume that $t = 100$ yr, what is a conservative estimate for R_b ? (Don't forget to include the units of R_b in your answer!) [2pts]

$$\text{If } t = 100 \text{ yr, and } N = 1, \text{ then } R_b = 0.01 \text{ yr}^{-1}.$$

66. On the Earth, the carbon dioxide cycle between atmosphere and mantle operates in such a way that it regulates its temperature. Use arrows as a shorthand to indicate the causal chain of events. Start with increased CO_2 and explain how this leads to less CO_2 . Next, explain how reduced CO_2 leads again to increased CO_2 levels. [6pts]

more $\text{CO}_2 \rightarrow$ more greenhouse gas \rightarrow warmer \rightarrow more evaporation \rightarrow more CO_2 gets dissolved in rain \rightarrow more acid rain \rightarrow produces more lime stone \rightarrow less CO_2

less $\text{CO}_2 \rightarrow$ less greenhouse gas \rightarrow cooler \rightarrow less evaporation \rightarrow less CO_2 gets dissolved in rain \rightarrow less acid rain \rightarrow produces less lime stone \rightarrow more CO_2 , and the whole process begins from the beginning.

67. A given strand of DNA is given by the following sequence of bases:

TAC TTC ACC GGG ATC.

- (i) What is the sequence of RNA bases that you would expect the above sequence would pair with? Hint: remember that letters match in specific pairs and T in DNA is the same as U in RNA. [2pts]

AUG AAG UGG CCC UAG.

- (ii) Using the table below, write down the amino acid sequence that this RNA sequence would code for. [2pts]

Met Lys Trp Pro Stop.

- (iii) Write down a mutated sequence of RNA bases that would result in the same sequence of amino acids. [2pts]

AUG AAA UGG CCC UAG.

and several other possibilities.

		Second Letter					
		U	C	A	G		
1st letter	U	UUU Phe UUC UUA Leu UUG	UCU UCC Ser UCA UCG	UAU Tyr UAC UAA Stop UAG Stop	UGU Cys UGC UGA Stop UGG Trp	U C A G	
	C	CUU CUC Leu CUA CUG	CCU CCC Pro CCA CCG	CAU His CAC CAA Gln CAG	CGU CGC Arg CGA CGG	U C A G	
	A	AUU AUC Ile AUA AUG Met	ACU ACC Thr ACA ACG	AAU Asn AAC AAA Lys AAG	AGU Ser AGC AGA Arg AGG	U C A G	
	G	GUU GUC Val GUA GUG	GCU GCC Ala GCA GCG	GAU Asp GAC GAA Glu GAG	GGU GGC Gly GGA GGG	U C A G	
						3rd letter	