I. Answers.

1. Why is it necessary for organisms to obtain energy?

   Energy necessary for biological activity: growth, maintenance, reproduction, movement, *etc.*; more generally to locally reverse 2nd Law of Thermodynamics (see below).

2. How do green plants obtain energy?

   From the sun via photosynthesis.

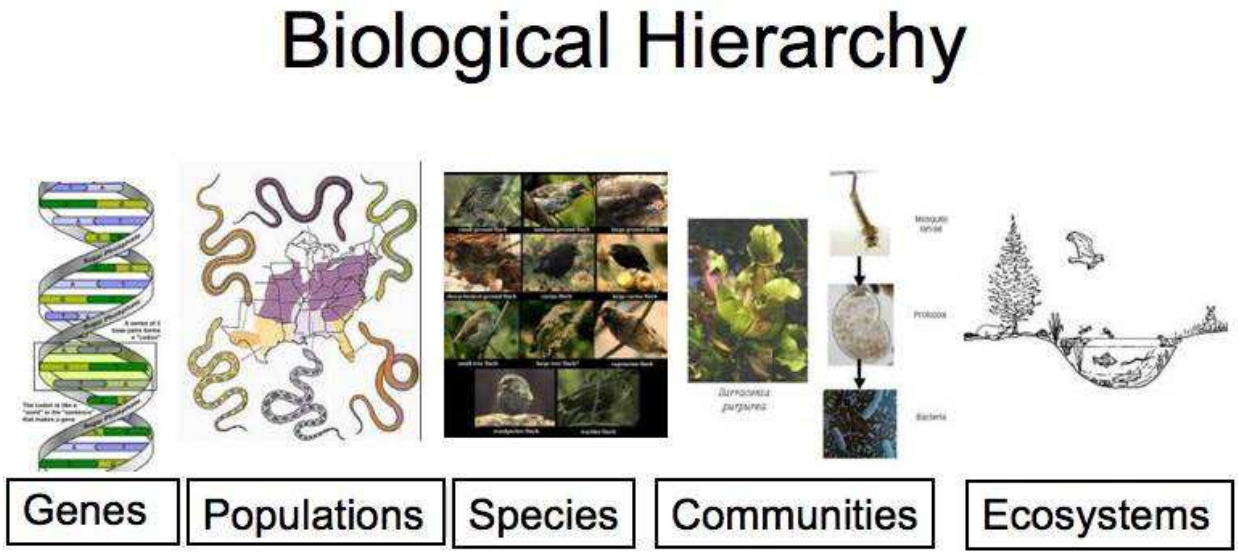
3. How do animals obtain energy?

   By eating plants or other animals (living or dead).

4. What is the ultimate source of energy for all animals and plants?

   Conventional answer is "the sun", *i.e.*, photosynthesis at the base of the food chain. However, as we will later discuss, many microorganisms extract energy from inorganic molecules. The atoms of which these (and all other molecules) are composed were produced in stars that later exploded.

5. The figure below shows some of the levels in the biological hierarchy discussed in introductory texts. List four additional levels that fit between genes and populations.



Organelles, cells, tissues, organs, individuals, family groups. The lowest level, "genes," would be better labeled "macromolecules."

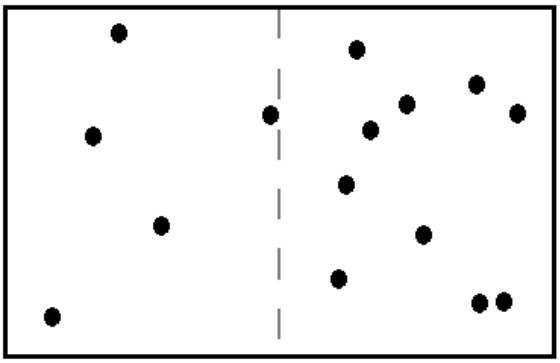
6. Disorder in the Department of Entropy. List three things you could do to reduce entropy in the office. What would each reduction require?

Repair the floor; re-hang the door, put the trash back in the wastepaper basket, *etc*. All require expenditure of energy.

7. Hoyle argued that the spontaneous origin of life on earth is incompatible with the Second Law. How might an evolutionist respond?

Evolution proceeds in small steps, each of which is accepted or rejected by selection when it first arises. Such a process proceeds much faster than if evaluation is deferred until all steps have been taken. For a whimsical analogy, go to http://bill.srnr.arizona.edu/classes/182/George.htm**.**

8. What are the values of p_1 and p_2 in the figure?



$p_1 = 1/3$; $p_2 = 2/3$.

9. Compute E for p_1 = .01, .10, .25, .5, .75, .9, and .99.

p_1	E	p_1	E
.01	**.0808**	**.75**	**.8113**
.10	**.4690**	**.90**	**.4690**
.25	**.8113**	**.99**	**.0808**
.50	**1.000**		

10. For what value(s) of p_1 on [0, 1] is E minimal?

    E(0) = E(1) = 0

11. For what value(s) of p_1 on [0, 1] is E maximal?

    E(0.5) = 1.0

12. Crudely, one can think of cells as "bags" of biological molecules that permit controlled molecular exchange with their environment. From the perspective of the Second Law, why should biological molecules be so packaged?

    According to the 2nd Law, chemicals diffuse down concentration gradients. Thus, a local concentration of biological molecules would be diluted (the biological molecules would diffuse out; water would diffuse in) absent a "bag" to maintain the local conditions distinct from those of the surrounding environment.

13. Why did Schrödinger imagine his information-bearing crystal to be aperiodic, *i.e.*, why wouldn't a "periodic" crystal (right) suffice?

    A periodic crystal can only code for a limited amount of information. In the case of periodic DNA, only a single amino acid could be encoded.

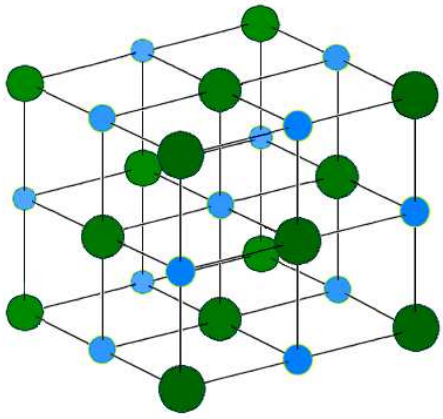


Table salt (NaCl) – a "periodic" crystal,

14. Schrödinger's crystal was later discovered to be **DNA**.

15. If cells from cells, whence cometh the first cell? Give two possibilities.

    Originated *de novo* on earth; transported to earth by comets, meteorites, *etc* (transpermia).

16. Viruses lack most of the structure of even the simplest cells. Whence cometh viruses? Give two possibilities.
    a. **Descended from pre-cellular (more primitive than a bacterium) life forms.**

    b. **Degenerate descendents of simple cells or their genetic material.**

17. In unicellular organisms, the cell is the organism; in multicellular organisms, cells are building blocks. How might the first multicellular organisms have evolved?

    Products of mitosis failed to separate.

18. If complete genomes are replicated when cells divide, how can one account for different cell types in multicellular organisms?

    Different genes turned on (or off) during development.

19. Does DWM necessitate a tree-like pattern of relatedness? Why or why not?

    a. **DwM assumes change, but does not necessitate splitting, *i.e.*., speciation.**

    b. **Tree of Life assumes that that lineages split but do not fuse. This is often the case. But there are exceptions. For example, as we will later discuss, new species can result from hybridization. Likewise, viruses can move genes from one species to another, and at least some of the organelles in eukaryotic cells are**

descended from formerly free-living prokaryotes. Finally, as we will later discus, the entire domain Eukarya may be the result of symbiogenesis.

20. With regard to natural selection, what is meant by "superior variations"?

    "Superior" refers to the relative contributions that different "varieties" make to future generations and therefore to reproduction and survival.

21. Who was Thomas Malthus?

22. If predators become sufficiently adept at detecting / catching / subduing / killing their prey, they will drive the latter to extinction. Give three or more reasons why this might not happen.

    a. **Counter-evolution by victims that can become harder to find / catch / subdue / digest.**
    b. **Ability of the predators to switch to alternative food species when victims become scarce.**
    c. **Predator densities kept in check by other factors.**

23. What do you think Darwin and Wallace might each have had to say about the little "yappers" (right) that inhabit retirement communities?

Darwin would have emphasized the breeder's ability to produce dogs that were deviated morphologically from a presumed wolf-like ancestor. Wallace would have emphasized that these creations are unfit. They only survive because humans provide food, shelter, *etc*.

24. Who was William Paley?

25. What was the teleological argument?

26. What was Paley's iconic example?

Regarding giraffes:

27. How might you attempt to further assess the relative merits of the two hypotheses? Hint: Think okapi (right)

The ancestor of savanna-dwelling giraffes resembled the much smaller okapi that lives in forests.

a. Compare the anatomical peculiarities (long tongue, anatomy of the skull) of giraffes with those of the okapi.

b. Study how neck length and head mass varies with body size in okapis and compare with the corresponding relations in giraffes.

c. Repeat #1 and #2 but using extinct species presumed ancestral to living giraffes.

28. Following publication (1996) of the paper in which it was first proposed, the sexual selection hypothesis quickly became a staple of introductory biology texts. What do you make of that?

Like the dinosaurs in *Jurassic Park*, scientists often move in herds.

29. As a general matter, what are some of the difficulties that attend determination of the adaptive significance of *any* character?

a. Difficulty (impossibility?) of specifying all selective pressures.
b. Difficulty (impossibility?) of specifying past selective pressures.
c. Complication of correlated characters / developmental constraints.

30. The theory of natural selection says that the fit survive – more accurately, that the fittest individuals make the greatest contribution to succeeding generations. If we compare successive generations and find differences in gene frequencies, morphology, *etc*., what are we to conclude? According to NS, the changes are due to differential survival / reproduction. But this is circular: the fit survive and the survivors are the fittest. How do you break the circularity?

Articulate hypotheses specific to characters in question; deduce predictions; test by experiment or observation. For example, there is a "trade-off" between the number of offspring that can be produced and the amount of energy

expended on each. The theory of "r-" *vs*. "K-" selection predicts that species living in unstable, ephemeral habitats should produce many, "cheap" offspring, whereas species living in stable habitats in which there is more competition should produce fewer, more "expensive" offspring.

31. Search on "Ptolemaic epicycles." What were they?

32. Does a model's ability to predict guarantee its correctness?

    No. One can, and often does, get the right answer for the wrong reason.

33. What does a scientist do when his predictions are confirmed by experiment – *i.e.*, after publishing his results?

    Deduce a new prediction that follows from his hypothesis and test it.

34. In physics, you study "laws" – Newton's, Kepler's, *etc*. What's a law?

    "Laws" are models that have been confirmed by so many experiments that most everyone agrees they are true. "So many" and "most everyone" remain undefined.

35. As a scientist, how should you respond when someone tells you that such and such will happen because a computer model predicts it?

    Observe that the output of computer models are nothing more than hypotheses, the validity of which can only be confirmed / rejected by observation and / or experiment. This is a problem with climate models.