

## Summary of Lecture 27

Key points include:

1. Life is abundant on Earth. Is there life other places in the universe? We don't know, but it's fun to speculate, and not impossible that such life will be discovered in our lifetimes.
2. As a starting point, we note that biological evolution, which is the unifying concept of biology, is so simple and general that it will work everywhere. We will therefore mention a few of its key aspects before moving on.
3. One thing that has caused confusion is that there are really two concepts which are both called evolution. These we can call the *fact* of evolution, versus the *theory* of evolution.
4. The fact of evolution is that forms of life change over time, via descent with modification. You're not identical to your parents; bacteria adjust to their environments (unfortunately for us in many cases, because they can become resistant to antibiotics), current-day horses don't look like their ancestors from tens of millions of years ago, and so on.
5. The theory of evolution has many details to it. But the basic idea is that the characteristics of a population are most strongly influenced by the individuals who leave the most viable offspring. Thus we have two essential components to the theory of evolution: (a) variation in a population (which can be due to mutation, sex, horizontal gene transfer, neutral drift, etc.; lots of possibilities), and (b) selection, which can be natural (some characteristics make survival less likely) or sexual (there can be preferences in mating).
6. The key to note is: variation is random, selection is *not* random. So if someone summarizes evolution by saying "it's all chance", they're wrong.
7. Disappointingly, there has historically been a lot of resistance to the idea that evolution operates on Earth. These objections typically come down to two misconceptions.
8. The first misconception is that if you accept the evidence for evolution you have to be an atheist (assuming that you think it is bad to be an atheist). But this is not true; many religious faiths have no problem with biological evolution.
9. The second misconception, weirdly, is that if we accept the evidence for evolution then we have to behave like "lower" animals. What??? Of course not. If you accept the evidence for gravity does that mean that you need to push people down stairs? Ethical guides come from other sources. Science describes how things are.

10. What we know about life on Earth is that the earliest forms of life appeared *really* early. There is indirect evidence for life from a good 3.8 billion years ago. The Earth is about 4.6 billion years, but until about 3.9 billion years ago the early Earth was getting pounded by planetesimals to such a degree that any life, if formed, would have been wiped out. So it seems that life basically formed about as early as it could have.
11. Life then evolved, with a variety of events including mass extinctions. Complex, multi-cellular life appeared relatively recently (maybe between 1 billion and 600 million years ago). Our existence was far from inevitable. For example, had an asteroid not hit the earth some 66 million years ago and done in most of the dinosaurs (all but those which evolved into birds), we wouldn't be here.
12. Single-celled life (e.g., bacteria) are everywhere there is liquid water; in the atmosphere, in the ocean, even deep in rock. Multi-cellular life is more fragile and requires more specialized conditions.
13. What does this tell us about life elsewhere? On Earth, we need liquid water and carbon for life. Is that true everywhere? We don't know!
14. Could there be life elsewhere in the Solar System? Maybe! There's liquid water (under ice) in a variety of places, including Jupiter's moons Europa and Ganymede. Earth is the only place in the Solar System with liquid water on its surface; is that needed?
15. People define the *habitable zone* as the distance a planet or moon needs to be from its host star to have the temperature needed for surface liquid water. There are plenty of exoplanets known in their star's habitable zone. Do they have life? We don't know. Is this even necessary for life? Europa is way out of the habitable zone, but maybe its sub-ice ocean can still have primitive life.
16. But what about aliens? Every now and then you get a claim, of an abduction or of UFOs (now called UAPs). Does that count as evidence?
17. No, not at the current level. It would be overwhelmingly transformative to discover that life exists elsewhere. That would be particularly true if we discover that such life is advanced and has been visiting us. Thus we need to demand the highest standards of evidence, and current claims don't meet that evidence. But we always need to keep an open mind.
18. My feeling is that simple life is so common on Earth that to me it seems inevitable that alien bacteria or whatever exist on other planets. I don't know the likelihood of advanced civilizations. Maybe we'll find out soon, maybe we won't find out for a long time. But let's see what we can learn!