Cellular Biophysics
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Biology by Numbers

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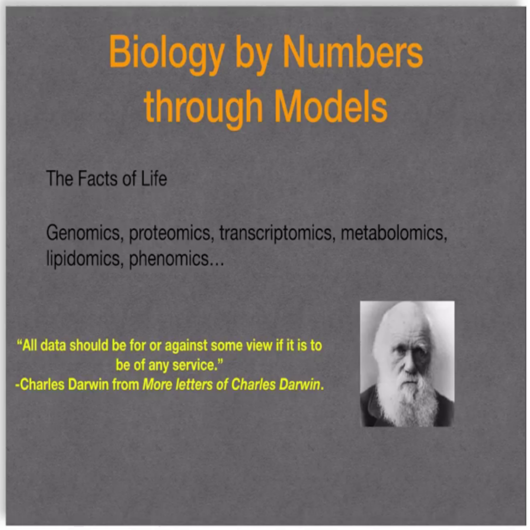

So far, we have dealt with a fundamental property of biological material in terms of water. Now, I want to move to something that is the core of this course, namely quantitative biology. Now, you will ask yourself, why should we quantitate biology. We see, frogs have four legs, birds have two legs, it is quite simple what is the point of quantification?

Now, one of the most important contributions to biology and concepts is the theory of evolution. And it was based on data, quantification if fact of bird beaks, their sizes, their frequencies, statistics, their biogeography, meaning variation across space, and fossils, meaning the variation across time.

Today in our current state of modern biology, we are very familiar with genomics, that is to say the high throughput and mass sequencing of large genomes, proteomics, which is identifying proteins across whole organisms, or cells or cell types, transcriptomics, which relates to measuring RNA expression, across 1000s, or millions of genes, metabolomics, which involves sampling, small molecules, metabolites, intermediates of the biochemical pathways across whole networks, which can be up to 10,000 to 50,000 components at a time, lipidomics, which is high throughput, whole lipidome, in other words, all the lipids produced in a certain organism or a certain cell type, phenomics, which relates to phenotypes, and so on and so forth.

These omics, as they are generally called, have led to huge proliferation of data. In fact, you could argue, one of the most prominent applications of data science today is in biology. But I am going to try to convince you that numbers alone are not useful unless we have models. In the previous segment, we talked about models for water, structure, hydrophobicity.

And now, I am going to take you through some ideas of numbers, which you must remember. Because while we always say that these are just facts, these give you a sense of how things relate to each other. Some people call this desert island science, which means that if you are stuck on an island with just a palm tree, and some fruit to eat, and no other person there, no computer, no paper, no pencil, and all you have is a stick and a beach on which you can write equations, then can you still think and do some science, this is nothing but intuition.

Now physicists, all the way back from Archimedes upwards, have always done this. And I am going to try and give you the tools by which you can also do this about biology, which is why this is also a biophysics course. So, I am going to begin biology by numbers through models, with the statement quoted from Charles Darwin, that all data should be for or against some view, if it is to be of any service.

In other words, data without a model makes no sense, it is just accumulating data, which is what we hope is not happening when people do genomics, proteomics, transcriptomics, etcetera.

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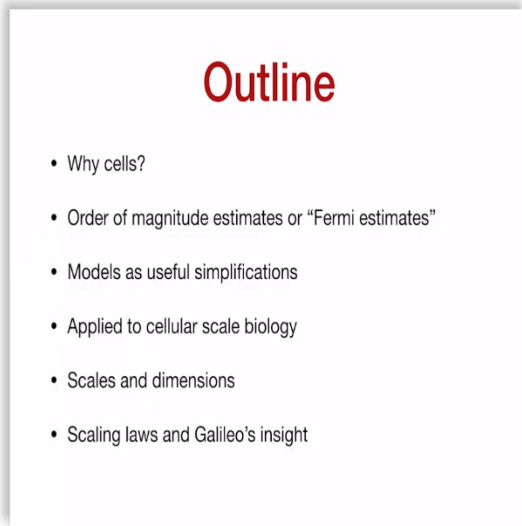

So, for this segment, I am going to ask and answer the question, why do we bother with focusing on cells, so you could argue that biophysics is not just about cell biology so why do we say it is cellular biophysics, what is the special property that makes us focus on this. Then I am going to ask what are order of magnitude estimates or Fermi estimates and how could do them.

And I will move on to models as useful simplifications and apply them at the cellular scale in biology, I will briefly touch upon something that we refer to as scales and dimensions. And I will end with scaling laws and the insights obtained from Galileo Galilei. For those of you remember, Galileo is considered the founder of modern classical physics. Interestingly, he also had some interest in biophysics. Let us try to reveal all these myths.

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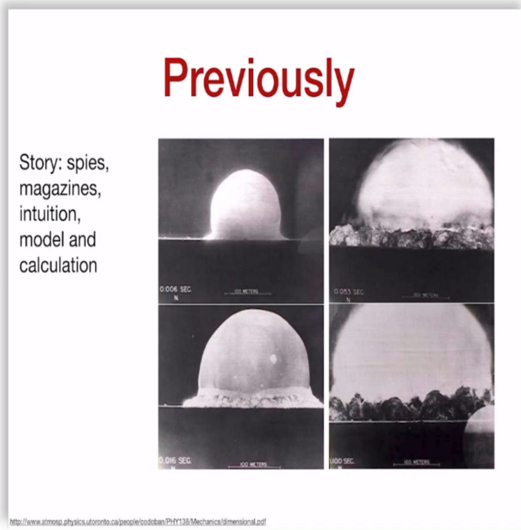

Now, in a long time past, that is the 1940s and 50s, there was a race between big powers between world powers for the most destructive tool that you can ever think of in physics, namely, the atomic bomb. What you are looking at here is a picture taken from the University of Toronto website of the explosion of a surface imploded device, nuclear device. And the famous mushroom cloud as it is sometimes called, in famous maybe, with a scale bar of 100 meters. It is important to note that these four pictures are taken from a magazine.

I think the magazine was Newsweek or Time. Now, I do not know if you remember this, maybe many of you are very young. But nuclear technology, at the time when it was invented, during the Second World War, was very tightly held secret. It was important that this technology is kept by those who have invented it to themselves. It is very destructive. As we know, from Hiroshima and Nagasaki, the only two usages of the nuclear bomb on human populations, and a very tragic destruction it was.

But these tests, these images that we are looking at are test images in a desert. Today, we also know so much more about the harmful effects of nuclear radiation. But if you go back 70 years ago, people were not as aware, because we did not know enough science of how radiation interacts with biological material, particularly DNA and causes mutations, and mutagenesis causes genetic diseases and genetic diseases cause very horrendous effects that last generations.

All this is manmade, of course, because there is a native amount of radiation in the earth. But this is completely man made by exploiting a nuclear weapon. So, in this explosion, the size of the mushroom cloud at 0.006 seconds, suggests that it is around 100 meters in diameter, that is around 0.1 kilometer, at about 0.053 seconds, that is 53 milliseconds, so the timing starts at 0, 0 there is nothing.

At 6 milliseconds, there is 100-meter diameter cloud. At 53 milliseconds, the cloud has increased to around 4 times that diameter. At around 16 milliseconds, sorry, so going top to bottom first, 6 milliseconds, 16 milliseconds, 53 milliseconds, and 1 second. In 1 second, the cloud has gone from 0 to about 500 meters across 0.5 kilometers across half a kilometer wide. You can imagine that if we give it a few more seconds, this cloud will expand rapidly.

And this is, there is a lot of very detailed information you can find on archival footage of the temperature and the shockwave and the radiation that comes from it. All these make nuclear weapons one of the most devastating and dangerous weapons in human imagination, and they can be used and they have been around with us thankfully, I hope I will pray that no one sees these in reality ever used, but when this picture was published not all the countries had nuclear weapons, only the United States of America had a weapon.

And a famous fluid mechanics researcher, Geoffrey Ingram Taylor saw this, and within a few days calculated and published a report describing how many kilotons the yield of this nuclear weapon explosion was. This was very exciting. But it was also strange because suddenly the United States Secret Service CIA, I do not think it was called that then came to his door and asked him How did you find out? Who leaked you the story? Who told you the information?

Well, Taylor was a smart physicist. And he simply showed them there is calculations because given this little bit of information this is promotional material, by the way, distributed by the Atomic Energy Agency, to all journals to show how proud they were about this weapon that they have developed. Taylor had done a good Fermi estimate or an order of magnitude estimate.

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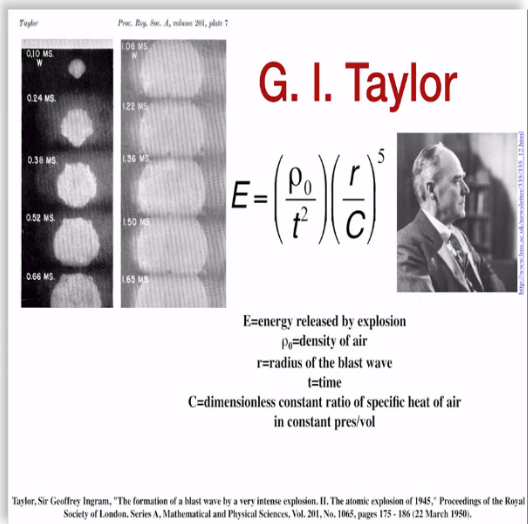

And the solution that arrived that is published in this paper Proceedings of the Royal Society of London series A, 1950 22nd March which is titled The formation of blast wave by a very intense explosion part to the atomic explosion of 1945.

$$E = \frac{\rho_0}{t^2}\left(\frac{r}{C}\right)^5$$

The equation that he arrived and derive from this data is E which is the energy released by the explosion is equal to the ratio of the density of the air, ρ_o by t^2 where t is the time, multiplied by r divided by c where r is the radius of the blast wave, remember I said the increasing wave diameter of the wave, so, half the diameter, divided by C which is a dimensionless constant of the ratio of specific heat of air in constant pressure volume, the second term is raised to the power 5.

Now, you should read the paper, he explains how we arrived at this particular expression, but given that the density of air is a well-known constant, the radius of the blast wave can be measured from the photographs and C is set from intuition, you can actually imagine that the time versus energy can be inferred that is fit from data alone, which is published in a magazine. This is powerful. So, you agree with me that this method of doing something like this.

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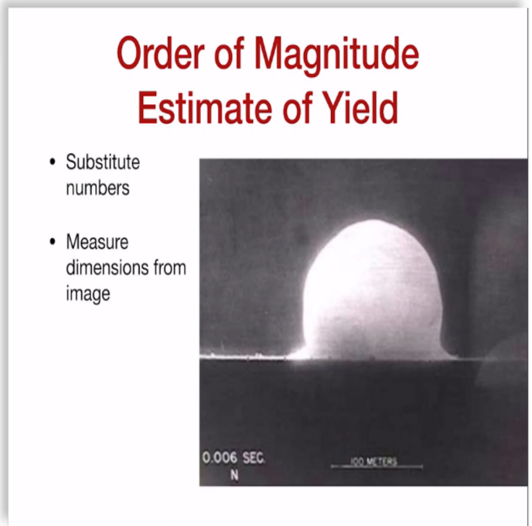

It deserves to be learned, so that we can apply it to more harmless things like biology. And this is called an order of magnitude estimate of yield based on dimensional analysis and some intuition. Now, for example, with this image if I asked you what is the diameter of this blast wave, you should be able to say it is approximately 100 meters, how do I know that the scale bar down there, I moved that scale bar on to the image and I can see that it is about 110 maybe meters in diameter, radius must be around 50 to 60 meters. But we need a bit more and that bit more is something I will discuss in the next module.

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And I will also ask you to do the same thing with a biological object, namely the cow or bull, one because they agronomically and culturally very important animals, and two because if you are in an Indian city you will see them everywhere. So, you have seen these but you have not thought about them in the way of biophysics.