Cellular Biophysics

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Tutorial - Part 01

Hi, welcome back. This is Cellular Biophysics. We were talking about fluids and how they are contrasted with solids and in the following few minutes I am going to discuss some problems and their solutions.

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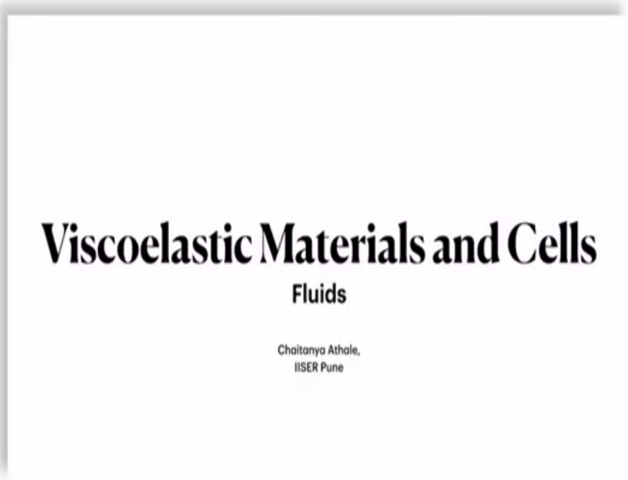

I am also going to talk to you about viscoelastic materials and cells.

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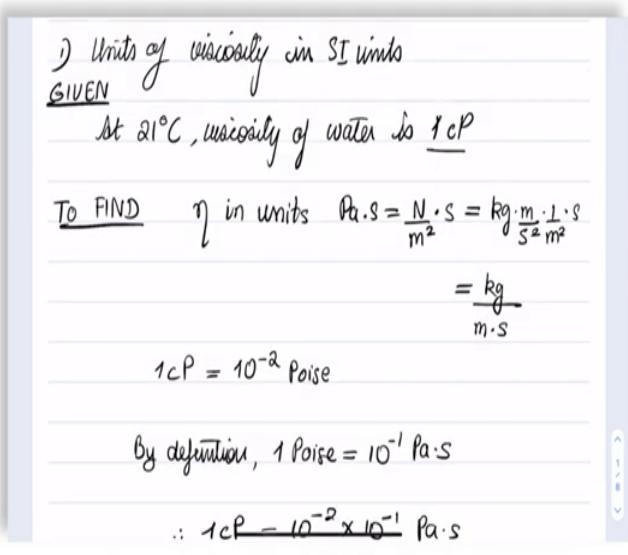

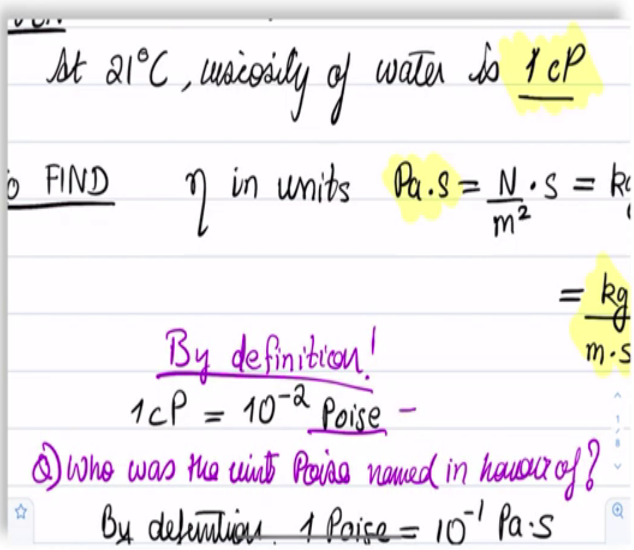

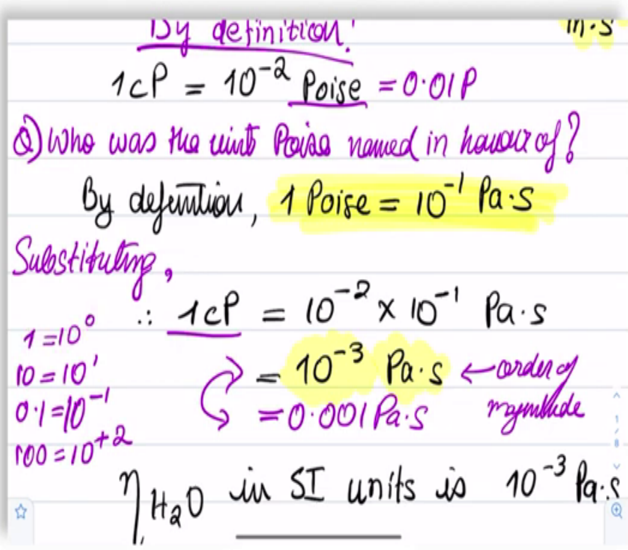

So, as it turns out we had mentioned that the viscoelasticity, sorry, the viscosity of fluids in SI units can be expressed in terms of standard values, which we know for water to be one centipoise. So, the question is can we find these values in SI units. For SI units we need to go back and look and it turns out they are Pascal seconds.

What this means is that we can also convert Pascal into Newton per meter square, Pascal is pressure, nothing but pressure, pressure per unit area, force per unit area into seconds, which converts to kg meters per second square that is mass into acceleration upon 1 by m square meter squared into seconds, which leaves you with kg per meter second or a Pascal second.

Either or can be used in terms of SI units. But if you want to know the value of water viscosity at 21 degrees Celsius, then we need to convert, for that we need to know - what is the conversion factor. Now, one of the reasons why we are familiar or we should be familiar with this term one centipoise, it is an easy number to remember at 21 degrees Celsius. If you go back to the literature and textbooks you will find 0.999 approximately to one.

So, one centipoise by definition, yes, is 10^{-2} Poise, by definition, it is the definition of one centipoise. Poise itself is in honor of the researchers who have contributed to fluid mechanics. As a pop quiz question into the history of fluid mechanics, I want you to find out who was the unit Poise named in honor of, in other words, what was this person, what did he or she discover, and why is this unit called that.

So, we can also write one centipoise is equal to 0.01 Poise, that is capital P. The second fact we need to know is the conversion from Poise to SI unit Pascal second. As it turns out one Poise is equal to 10 to the power minus 1 Pascal second. So, now our job becomes one of substitution, where we can now write one centipoise is equal to let us say 10 to the power minus 2 Poise, Poise itself is 0.1 Pascal seconds, 10^{-1} Pascal second.

And hopefully you are doing this on your own or you are looking or you are thinking, the answer, therefore to answer the question what is the conversion factor from 1 centipoise to 2 SI units for the viscosity water is 0.001 Pascal second, which we find in biophysics, much more convenient to write as 10^{-3} Pascal second.

These two are obviously identical. You know that this refers to the order of magnitude and it is derived from the idea that I can write 10 as 10^{1}, 0.1 as then 10^{-1}, 100 as 10^{2} and so on. What is 1? 10 to the power 0. So, these are elementary things, you know these, but you need to remember them because it comes in very handy, because I remember it is very hard to know if I write this value here.

How many zeros are there and I have to sit and count and so on and so I write 10 to the power minus 3 it is much cleaner, much easier to read and objective. So, the viscosity of water in SI units is 10 to the power minus 3 Pascal second at 22 degrees Celsius.

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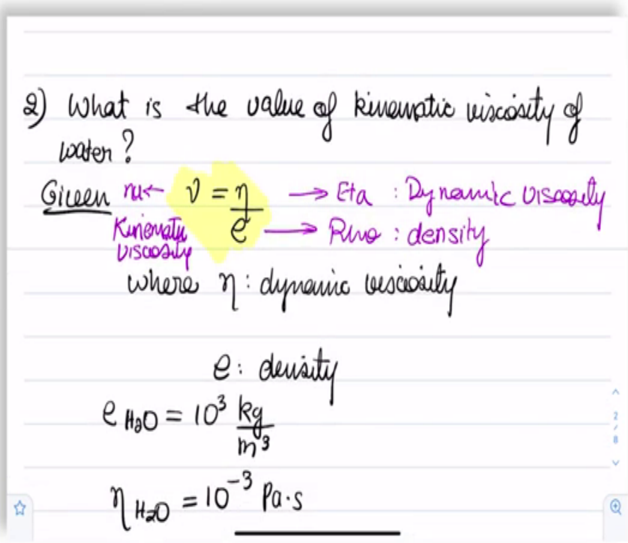

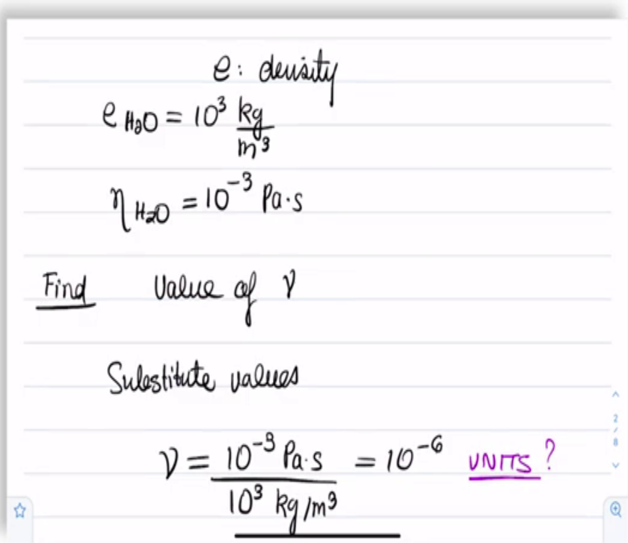

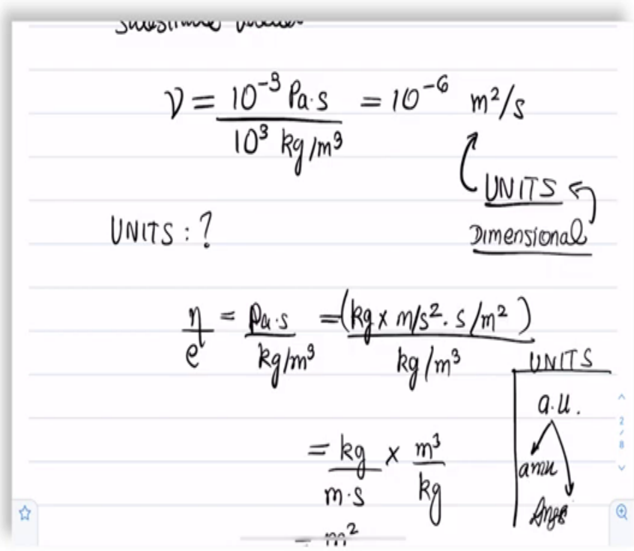

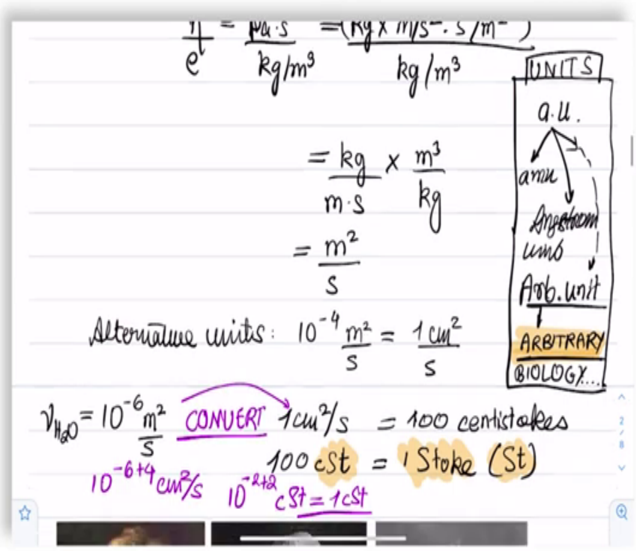

The viscosity of water can also be expressed in terms of the kinematic viscosity. So, the next problem relates to the question what is the value of the kinematic viscosity of water. Now, you may recall that in our previous lectures we have defined kinematic viscosity as ν is equal to η by ρ.

$$\nu = \frac{\eta}{\rho}$$

These are all Greek letters. Now, ρ means density as you all know, η is what we have just talked about dynamic viscosity and ν is the symbol for kinematic viscosity.

So, in other words, this new term is just simply the ratio of the dynamic viscosity to density. You can think of it as a measure of viscosity relative to the density of a substance. In other words, if the density of the substance increases, then the kinematic viscosity or how fast things can go in it will decrease and if the density of the fluid decreases then the kinematic viscosity increases for the same η value.

So, by definition η is dynamic viscosity, ρ is density. We need numbers for this, so we are also going to take into consideration the fact that density of water at a room temperature or standard temperature and pressure is 10^3 kgs per meter cube, thousand kg per meter cube. The viscosity of water as we saw right now, the dynamic viscosity is 10^{-3} Pascal second. Just keep this in mind.

Now we are basically talking η by ρ, which means 10^{-3} upon 10^3, if we substitute the values we end up with 10^{-6}, wonderful. All this was in SI units, so we must ask ourselves what are the units that we use. So, we need to go back to our definition of Pascal second in terms of kg meters per second square and substituting the values, we end up with kg upon meter per second into meter cube by kg which gives us a meter square per second.

So, this is 10^{-6}, and now we can write the units as meter square per second. Remember dimensional variables, we all must, we always must mention units. You may sometimes in biological literature find a unit au, so some of you will probably know that it sometimes refers to amu, atomic mass unit, it may just refer to Angstrom unit, which are both bona-fide units, but sometimes it is a false unit.

Sometimes people write it as Arb unit. Arb means arbitrary. This is a warning bell for all of us, because from a biophysics perspective there is no such thing as an arbitrary unit and I would recommend strongly avoiding such usage. Now, it is true that sometimes in biology it is hard to find calibration units and therefore, units are referred to as arbitrary units because there is no unit in other words.

It is worthwhile contemplating how we can convert arbitrary units into physical units, and this is in some senses the real goal of quantitative biology. So, coming back to kinematic viscosity, we can also write kinematic viscosity in terms of centimeter square per second. For water the kinematic viscosity is 10 to the power minus 6. The conversion factor from meter square per second to 1 centimeter square per second is 10^{-4}, this is due to centimeter to meter conversion and the power of 2.

1 centimeter square per second is also 100 centistokes and a 100 centistokes is 1 Stoke also written by St. Just like we saw Poise and centipoise earlier, so we now have Stokes and

centistokes. These are specific units that are invented in some sensors to deal with the small numbers that show up. Let us try a fun exercise.

If nu H2O is equal to in SI units 10^{-6} m^2/s how much is it in centistokes and stokes. So you need to convert from these to these units. Remember when we are going to meter square to centimeter square we will multiply, so meter square to centimeter square is 10^4, so we end up with 10^{-6+4} centimeter square per second, which is equivalent of a 100 centistokes.

Which means it is 10^{-2+2} centistokes which is equal to 1 centimeter stroke. So I hope you see the value of using centistokes because the kinematic viscosity of water comes to 1.

You recall that we did something similar with centipoise, where we said that 10^{-2} Poise is 1 centipoise and one Poise is 10 to the power minus 1 Pascal second, viscosity of water is 1 centipoise and that turns out to be 1000 or 10 to the power minus 3 Pascal second. So in a similar manner to keep things simple 1 centistoke ends up being this kinematic viscosity of water which in turn is 10^{-2} Stokes.

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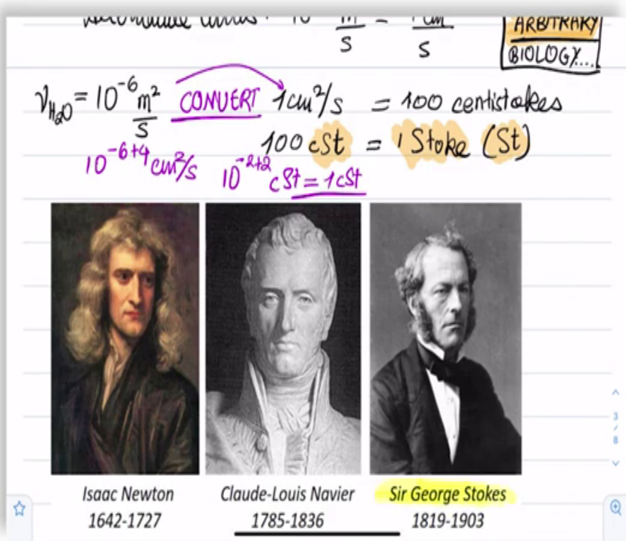

Stokes Timeline

1819 – Born County Sligo Parish of Skreen

1837 – Entered Pembroke College Cambridge

1841 – Graduation, Senior Wrangler, Smith's Prize, Fellow of Pembroke

1845 – Viscosity

1845 – Viscoelastic solid and the luminiferous ether

1845 – Ether drag

1846 – Review of hydrodynamics (including French references)

1847 – Water waves

1847 – Expansion in periodic series (Fourier)

1848 – Jelly theory of the ether

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1849 – Lucasian Professorship Cambridge

1849 – Geodesy and Clairaut's theorem

1849 – Dynamical theory of diffraction

1850 – Damped pendulum, explanation of clouds (water droplets)

1850 – Haidinger's brushes

1850 – Letter from Kelvin (Thomson) to Stokes on a theorem in vector calculus

1852 – Stokes' 4 polarization parameters

1852 – Fluorescence and Rumford medal

1854 – Stokes sets "Stokes theorem" for the Smith's Prize Exam

1857 – Marries

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1852 – Fluorescence and Rumford medal

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1857 – Marries

1857 – Effect of wind on sound intensity

1861 – Hankel publishes "Stokes theorem"

1880 – Form of highest waves

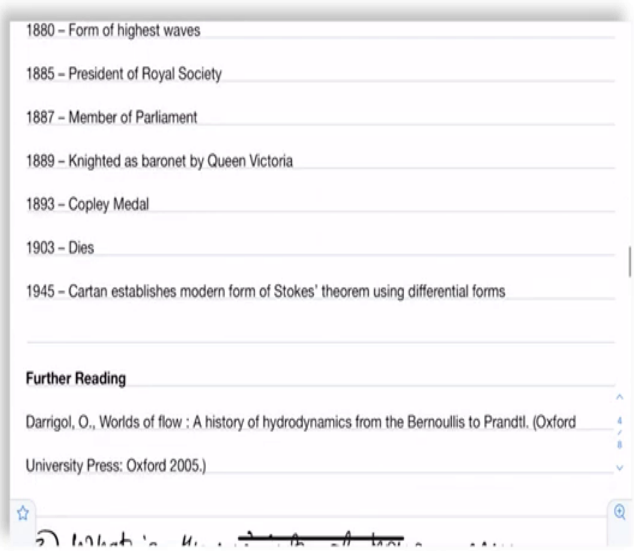
1885 – President of Royal Society

1887 – Member of Parliament

1889 – Knighted as baronet by Queen Victoria

1893 – Copley Medal

1903 – Dies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1945 – Cartan establishes modern form of Stokes' theorem using differential forms

Further Reading

Darrigol, O., Worlds of flow : A history of hydrodynamics from the Bernoullis to Prandtl. (Oxford University Press: Oxford 2005.)

So, who is Stoke and why did the name come? Again general knowledge, who are these people. Left to right, I think you recognize the left person, Isaac Newton, who wrote Principia Mathematica Denature, The Foundation of Modern Classical Mechanics, along with Galileo. The second and third from left, this person and this person, they are interesting. Claude-Louis Navier and Sir George Stokes. And the stoke is in honor of this last person George Stokes.

Indeed the timeline of Stokes was that he was born in 1819, entered Cambridge University and started working in 1845 on viscosity, viscoelastic solids, drag, hydrodynamics, water waves, Jelly theory and Geodesy and Clairaut's theorem. He also worked on diffraction, damped pendulum, clouds, water droplets, in a way he was a polymath.

He did many different things and you can read more about his historical contributions to modern physics, in terms of a history of hydrodynamics from Bernoulli to Prandtl in a book by Darrigol and company.

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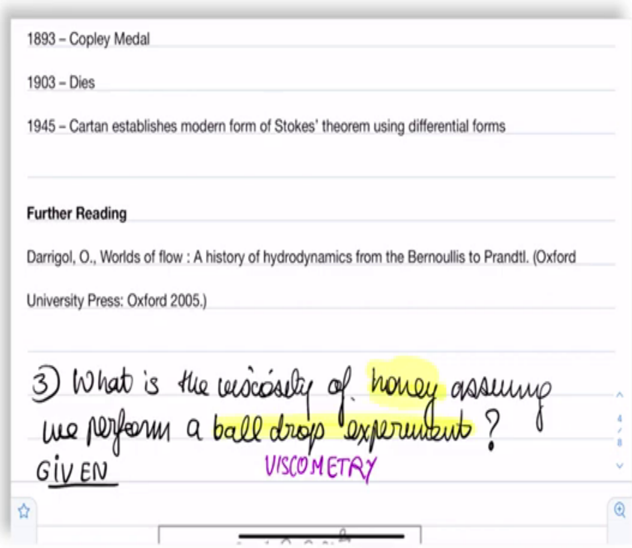

The next question we want to answer is - what is the viscosity of honey assuming we perform a ball drop experiment. So here, we are going to combine two things that we have already learned about ball drop viscometry and a very viscous fluid, everyone who has had the opportunity of looking at honey knows that it is both very dense and very hard to deform fluid.

So, in order to get a number we will need to do a ball drop experiment. Now, this is not an experimental lab, this is a classroom, so we will take data from other people's work and try to infer the viscosity.