TEACHER NOTES – ASTRONOMY IN THE NEWS #08

VENUS CLOUDS TOO DRY FOR LIFE?

Slide 2 – Background Science: Is there life in the clouds of Venus?

In September 2020, a potentially exciting result was communicated to the astronomy world, the presence of phosphine gas in the clouds of Venus. Phosphine, PH_3, is found naturally in the Earth's atmosphere at very low abundances. The most likely formation route is the decaying of organic matter. As a result, the discovery of significant enough quantities of phosphine in the clouds of Venus was an exciting result that may indicate life. The team who produced this result tried to analyse the result away and tested the following production methods of phosphine, but none were able to replicate the observed quantities:

- Steady-state chemistry
- Photochemical activity
- Lightning activity
- Volcanic activity
- Meteoritic delivery

This left the possible scenarios as an unknown chemical process, or originate from life.

Since the publication of this result, numerous studies have tried to disprove these findings. They have included debating the validity and significance of the detected phosphine lines in the observed spectra from the two telescopes used, to replicating their results (and observed abundances) using different assumptions on initial elemental abundances or a detection of SO_2. The research described in this resource will also come to the conclusion that the observed phosphine does not originate from life but from a different approach. That will be described in Slide 3.

Venus is a harsh environment which is thought to be too hot for organic life at the surface of the planet. However, at altitudes of 40-70 km, the temperatures are thought to be suitable for life. The range of temperatures found to allow for metabolic activity on Earth is -40 ^{o}C and 130 ^{o}C.

Another property that is key to metabolic activity is "water activity". Water activity is the ratio of the vapour pressure of the solution that the water is in to the vapour pressure of pure water at the same temperature. Pure distilled water would give a ratio of 1, the maximum value. A higher value encourages metabolic activity, with lower values too dry to allow this. It does not necessarily kill life, but it does stop activity. The limit found for metabolism on Earth is 0.585.

IMAGES:

1. (Top left) Ranges of water activity where metabolism is observed on Earth for different types of life. Bacteria is limited to values above 0.75, whilst Eukarya are able to metabolise down to levels of 0.585. (This figure shows the old value of 0.605).
2. (Top middle) Venus image taken in the ultraviolet wavelengths from the NASA Pioneer Venus Orbiter. These wavelengths reveal the cloud structure in the atmosphere.
3. (Top right) Model of the temperatures found on Venus as a function of altitude, with the measured temperatures indicated by the red line. Life on Earth shows metabolic activity between temperatures of -40 ^{o}C and 130 ^{o}C, which is in the altitude range of the cloud layers on Venus.
4. (Bottom) The spectrum from the James Clerk Maxwell Telescope at the wavelength associated with PH_3. The red line is a model that would show the abundance of SO_2 required to replicate the observed absorption. SO_2 is postulated to be the cause of the observed spectrum but the authors of the original Venus cloud paper (Greaves et al.) argue that an abundance that is six standard deviations above the usually observed abundance would be required to replicate the spectrum. (My opinion on this spectrum is that it's hard to argue there's a detection at all, and you can see why there is such debate over the result.)

Slide 3: Are the clouds too dry?

The first assumption made was that life on Venus would require the same conditions as Earth. This may not be the case, but it's the only assumption that can be made.

The clouds of Venus contain very high concentrations of sulphuric acid, with various concentrations found. A high concentration of acid is not necessarily a barrier to life, with an archaeon found on Earth growing at a pH of -0.06. This, however, only corresponds to a concentration of 11.6%. The concentrations of sulphuric acid found on Venus are between 77.8 and 99.2 %. Terrestrial life cannot handle these concentrations of acid, so the conditions for life on Venus would have to be fundamentally different to Earth.

The temperatures suitable for life, -40 ^{o}C and 130 ^{o}C, and concentrations of sulphuric acid had water activities calculated, with intermediate values extrapolated from models. By comparing these calculations to the measured sulphuric acid concentrations, the current water activities can be derived. These values were found to correspond to water activities of 0.00003 to 0.0037. These are much smaller than those found on Earth that allow for metabolism, and is a large distance thermodynamically to bridge for life on Venus to be significantly different than that on Earth. For the cloud droplets to be habitable, water activity would have to be strongly out of equilibrium compared to the rest of the clouds, which is not thought to be the case. The fact that the water activity is so low, means the clouds are too dry to support life.

However, by making these calculations on other planets, the conditions in the clouds of Jupiter could be suitable for life as the values of water activity found are permissible for life.

On Mars, water activity in clouds is found to be slightly below the permissible range due to the presence of ice, while on Earth clouds are habitable until the middle stratosphere.

The article that this resource is built off can be found here:

https://www.bbc.co.uk/news/science-environment-57641247

A free version of the research paper that is described can be found here. I would note that I do not know how this article will remain free:

https://www.nature.com/articles/s41550-021-01391-3.epdf?sharing_token=8-whW4dj0cJU8ONKGVLOCNRgN0jAjWel9jnR3ZoTv0O225BglaFMXCIxxPfj3DGxnDVdSSCxgC2UkwjZZg1Pl9WXxavsSg9m45Y3xe8kbUQ24pgCL4KNT6A1ndpBMhxYebsljCyQA3woieM-AvFPquvBHSE09VBRROc1wklWetGF9VwNWk8leuXs6ua4HTStJB-TwnbsJZsAYXbVRBTGRmN3s8Ykv_hFWBwP9AIf4Jo%3D&tracking_referrer=www.bbc.co.uk

IMAGES:

1. (Left) Sulphuric acid concentrations vs. temperature, with the associated water activity represented by the colour scale. These values are calculated from laboratory experiments, and the temperature range given is -40 ^{o}C and 130 ^{o}C. On top of the colour scale are some lines representing various values. The most extreme line to the left is a pH of -0.06. This is the acidity limit to metabolic activity for life found on Earth. The other lines are lines of constant water activity. The furthest left is 0.585, the limit on Earth with those to the right representing 0.01, 0.001, and 0.0001. The observed sulphuric acid concentrations on Venus are represented by the grey dots. This demonstrates that the water activity values on Venus are too dry to allow for metabolism.
2. (Right) Water activity vs. altitude on Venus. This shows the altitudes at which there is an increase in water activity, but as evidenced by the previous plot, these are still too long for metabolism.
3. (Centre) Temperature vs. water activity in the clouds of Jupiter at an altitude where water, due to the pressures involved, is in liquid form. This demonstrates that the water activity would be suitable for metabolic activity where temperatures are between -40 ^{o}C and 10 ^{o}C.

Slide 4 – Activity: Discussion Activity

The activity for this week is a discussion of some of the results that are presented. The three questions on the slides are:

- How do values of pH become negative?
- Do you believe the detection of phosphine, is it a significant feature in the spectrum?
- If the phosphine is not caused by metabolism, what other processes could cause it?

The first question is answered because of how pH is calculated. This is a difficult question but explains to the students that the range of pH is not limited to the one they are taught.

pH is the negative of the power of 10 of the hydrogen ion molar concentration. Therefore, a one mole solution has a pH of 0. However, an acid solution that is more than one mole can give a negative value. The same is true for alkaline solutions past the limit of pH = 14.

The second question tests statistical significance and whether the students think that the absorption feature is much more significant than the ripples caused by noise.

The third question asks the students to come up with physical processes that can cause chemical reactions. These include lightning, volcanic activity, and other regular chemical reactions.

GCSE Specifications:

Specification	Knowledge Point
Pearson Edexcel Biology	1.9, 8.9
Pearson Edexcel Chemistry	3.1, 3.4, 3.5
Pearson Edexcel Combined Science	B1.9, B8.9, C3.1, C3.4, C3.5
OCR Biology B	3.1.3
OCR Chemistry B	5.4.6, 6.1.6, 6.1.7
OCR Combined Sciences B	B3.1.3, C5.4.6, C6.1.6, C6.1.7
AQA Biology	4.2.2.1
AQA Chemistry	4.4.2.4, 4.4.2.6
AQA Combined Trilogy	4.2.2.1, 5.4.2.4, 5.4.2.6