Chemistry update
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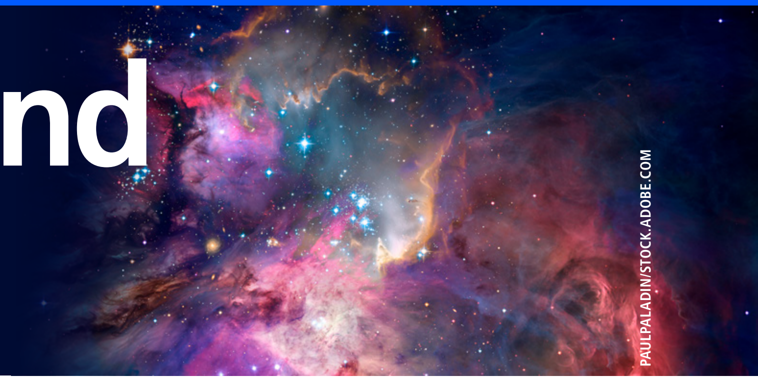
Chemistry and the cosmos



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Are we alone in the universe? It is a question that has puzzled not just scientists but many of the residents of planet Earth. **Joseph Lloyd** explains.

Given the vast expanse of the universe, the number of galaxies within it and the number of stars within those galaxies, the statistics would suggest that the existence of extraterrestrial life is a definite possibility. While conclusive proof eludes us, scientists have found tantalising clues that life in space could exist. As space technology advances, we gain more and more insight into our cosmos and the possibility of life beyond our own planet.

A telescope's toolkit

The James Webb Space Telescope (JWST) was launched on Christmas Day 2021. Its mission is to conduct infrared (IR) astronomy, investigating anything from the formation of early galaxies to the characteristics of distant planets. It is equipped with an Integrated Science Instrument Module (ISIM), which holds four instruments:

- Near-Infrared Camera (NIRCam): covers the IR wavelength range from 0.6 to 5 microns (μm), detecting light from the formation of early stars and galaxies and young stars in the Milky Way.
- Near-Infrared Spectrograph (NIRSpec): observes the same wavelength range as NIRCam, but the spectrograph disperses light from an object into an IR spectrum, allowing scientists to determine its physical properties.
- Mid-Infrared Instrument (MIRI): this is both a camera and a spectrograph. It can therefore detect wavelengths between 5 and 28 microns and disperse them into a spectrum. It detects distant galaxies, the birth of stars and faintly visible comets.
- Near Infrared Imager and Slitless Spectrograph (NIRISS): detecting in a wavelength range of 0.8 to 5 microns, this instrument can detect and characterise exoplanets (planets that lie beyond our solar system).

It is this last instrument, the NIRISS, that is key to determining the potential for life beyond Earth.

Light and life

When the Hubble telescope first discovered K2-18 b, an exoplanet, there were hopes it could also be a Hycean planet; a planet with a hydrogen-rich atmosphere and a surface covered in an ocean of liquid water. Given that it orbits within the habitable zone of a cool dwarf star called K2-18, optimists wondered if this could be the place where conclusive proof of alien life might be found.

More recently, the JWST has inspected K2-18 b and discovered that it holds simple, organic molecules in its atmosphere, further raising hopes of discovering life. Initial observations suggest an abundance of methane and carbon dioxide, as well as a shortage of ammonia. How do the astronomers using the telescope know that a planet more than 120 light-years away has an abundance of methane and carbon dioxide in its atmosphere?

Covalent bonds in organic molecules absorb certain frequencies of IR radiation. If an organic molecule is irradiated with a frequency of IR energy that matches the vibration frequency of its bonds, it

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absorbs that energy and the amplitude of vibration increases. This is called the resonance frequency and allows chemists to determine what functional groups are present. Other frequencies pass by unaffected.

Certain frequencies of light from K2-18 b are blocked or absorbed. Those absorbed frequencies indicate the presence of bonds and therefore certain molecules. In this case, methane and carbon dioxide. Scientists suspect that dimethyl sulfide could also be present. On earth, this molecule only comes naturally from one place, phytoplankton (tiny aquatic plants). Could it be that an ocean of water is supporting similar lifeforms 120 light-years away from Earth?

The search continues

K2-18 b may lie within the habitable zone and host simple organic molecules, but it is highly unlikely to harbour life. The exoplanet is around 2.6 times the size of Earth, implying the presence of an extensive atmosphere more like Neptune's than Earth's. With such a thick atmosphere, the temperature and pressure increase as we get closer to the planet's surface. Here the pressure and temperature are likely to be thousands of times higher than on Earth, making the existence of complex molecules that are essential to life near impossible. Furthermore, while an abundance of methane and carbon dioxide, as well as a shortage of ammonia, support the presence of water, the planet could be too hot for the water to be in a liquid state.

Conservative estimates only allow for one or two planets capable of supporting civilised life in a typical galaxy. Yet estimates also suggest the existence of around two trillion galaxies in the observable universe and more beyond what we are capable of seeing. Therefore, while K2-18 b is unlikely to host life, the statistics still point to trillions of potential civilisations existing elsewhere in the universe. Of those trillions of possibilities, scientists have so far studied mere thousands. Who knows, perhaps alien scientists many light-years away are training their instruments on the third planet orbiting a yellow dwarf star across the galaxy and wondering if it harbours intelligent life like them.

Questions

1 You are given three samples of gasses: methane, carbon dioxide and hydrogen. How can you differentiate between them using IR spectroscopy?

2 Convert the detection range of MIRI from microns to wavenumbers. (Hint: a micron is also known as a micrometre, μm)

Answers

1 Carbon dioxide has two C=O bonds. The IR spectrum will show absorption between 1630 and 1820 cm^{-1}.

Methane has four C–H bonds. The IR spectrum will show absorption between 2850 and 3100 cm^{-1}.

Hydrogen has one H–H bond, but it is a symmetrical molecule and so does not have a permanent dipole. It is therefore IR inactive.

2 Wavenumber is equal to the reciprocal of wavelength.

To find the reciprocal of *x*, we divide 1 by *x*.

A micrometre is equal to 1×10^{-6} m, i.e. 0.000001 m, or 0.0001 cm.

MIRI detects wavelengths between 5 and 28 micrometres (0.0005 to 0.0028 cm).

This is equivalent to 2000 to 357 cm^{-1}.

Resources

Infrared spectrum of the atmosphere of planet K2-18 b: **https://tinyurl.com/jszb9kvh**