TEACHER NOTES – ASTRONOMY IN THE NEWS #43

WATER ON AN ASTEROID

Slide 2 – Background Science: Origin of Water on Earth

Water covers about 70% of the surface of the Earth and is essential to life on Earth. However, the origin of the water is not well understood with three prevailing theories.

The first is that carbonaceous chondrites and other icy planetesimals accumulated on Earth about 4.5 billion years ago as the Earth grew from 60%-90% of its current mass to now. These objects would have brought water to Earth, and a significant number of collisions would have eventually built the abundances of water. The strengths of this argument are that the deuterium/hydrogen isotope ratio found on these objects is similar to that found in ocean water, and the fact that rock samples from the Apollo missions show chemical compositions similar to the Earth. The fact that this occurs indicates water must have been present on Earth at the time of the formation of the Moon.

The second is that water was delivered much later in the process, after the formation of the Moon. The reason for the requirement of this is that the noble gas isotope ratios are different in the mantle compared to the atmosphere, indicating that they formed from different sources. However, since the amount of mass accreted after the Theia collision is very low, these objects must have been very water-rich, which could be possible if icy asteroids were impacting the Earth due to Jupiter migrating closer to the Sun.

The final hypothesis is that it was, in fact, the collision with Theia that created the Moon that brought water to the Earth. If this object formed in the outer Solar System rather than in the inner Solar System, it would have been water and carbon rich, and this collision would have provided a lot of water to the Earth.

IMAGES:

1. (Top left) Image of Earth showing the water on the surface that we all know exists!
2. (Bottom left) Image of a carbonaceous chondrite, the type of meteorite in question in Slide 3, along with the suspected origin of a fraction of the water on Earth.
3. (Right) Cartoon depiction of the collision between the Earth and Theia, the planet the size of Mars that is hypothesised to have collided with Earth to form the Moon 4.5 billion years ago.

Slide 3: Water on asteroid Ryugu

The Hayabusa2 satellite visited the asteroid Ryugu, or the full name 162173 Ryugu. By doing so it completed multiple scientific experiments, including three rovers which collected samples and made scientific measurements, such as of the magnetic field. Along with this, the satellite also made a visit to the surface, collected a sample of dust and soil, which was returned to Earth for analysis. Due to the success of the mission, the lifetime was extended to go and study another asteroid.

The sample was analysed in a laboratory and was found to contain several molecules that had water inclusions. Inclusions, in chemistry, are where a molecule has a cavity and within this cavity a molecule can be found. They are held in by van der Waals forces, the forces responsible for intermolecular bonding (such as an ammonia molecule with another ammonia molecule). The samples were also rich in carbonates, molecules derived from carbonic acid or carbon dioxide, and these were formed by alterations with water at low temperatures and the water/rock ratios found here. The asteroid is thought to have formed outside of the orbit of Jupiter and shows that these objects do contain significant amounts of water. As discussed above, this is a theory of how water originated on Earth, and these results demonstrate that this is a viable route to this occurring.

The article that this week's bulletin is built on can be found here:

https://www.theguardian.com/science/2022/sep/22/water-found-in-asteroid-dust-may-offer-clues-to-origins-of-life-on-earth

IMAGES:

1. (Top left) Cartoon image of the Hayabusa2 satellite collecting the sample from Ryugu to return to Earth.
2. (Bottom left) Image taken of Ryugu from 40km away by the Hayabusa2 satellite. As you can see, although only roughly 1km across, it has a lot of structure including multiple boulders spread across the object.
3. (Right) Chemical modelling of the minerals found in the returned sample. The initial compositions were selected to be consistent with the returned abundances, along with those of the general population of objects. Since they have discovered water-impacted minerals in the sample, they assumed a temperature of 0 to 40 °C, which is consistent with the melting required. They found that the abundances were consistent with H_2O and CO_2 gases, with a solution of magnesium, sodium, and chlorine. The fact that these abundances are found indicates it was formed at distances outside of the orbit of Jupiter.

Slide 4 – Activity: How many water-bearing asteroids hit early Earth?

This week's activity is an exercise in guesstimating. If we assume that water was only brought to Earth by water-bearing asteroids, how many times was Earth hit in its early life. The pupils should first make a guess.

I then show some numbers. A recent estimate of the approximately 20,000 near-Earth asteroids was that they contained 400 billion litres of water (so, roughly, 20 million litres per asteroid). If Earth contains 1200 quintillion litres of water (1200×10^{18} litres), how many collisions would have happened to bring that amount of water. The answer is truly amazing at 6×10^{13}. Now this seems like a lot, and it is, but the Solar System was a much different environment then than it is now. For a start, there were rogue Mars sized objects that were travelling around that could crash into planets!

GCSE Specifications:

Specification	Knowledge Point
Pearson Edexcel Astronomy	9.5, 11.1, 11.10, 11.13, 11.27
Pearson Edexcel Physics	6.3, 6.4
Pearson Edexcel Chemistry	1.9, 1.26, 1.34
Pearson Edexcel Combined Science	C1.9, C1.26, C1.34, P6.3, P6.4
OCR Physics B	5.1.5, 5.1.6, 5.2.4
OCR Chemistry B	1.1.3
OCR Combined Science B	C1.1.3, C5.2.4, P5.1.5, P5.1.6
AQA Physics	4.4.1.2
AQA Chemistry	4.1.1.5, 4.2.1.1, 4.4.2.2, 4.4.2.3, 4.4.2.6
AQA Combined: Trilogy	5.1.1.5, 5.2.1.1, 5.4.2.2, 5.4.2.3, 5.4.2.6, 6.4.1.2
WJEC Chemistry	1.2(e)
WJEC Double Award	2.2(e)
SQA National 5 Chemistry	Isotopes, Acids and Bases
CCEA Physics	1.5.7, 1.5.24
CCEA Chemistry	1.1.10, 1.3.4, 1.8.13
CCEA Double Award	C1.1.10, C1.3.4, C1.8.13, P1.5.7, P1.5.24

A-Level Physics Specifications:

Specification	Knowledge Point
OCR Physics A	6.4.1(d)
AQA Physics	3.2.1.1