Lesson 12  Priestley’s Bell Jar Reading

Unit Question: How can trees reduce climate change?

Lesson 12  Priestley’s Bell Jar Reading: Do trees really change the composition of the atmosphere around us?

A paradigm of fragile Earth in Priestley's bell jar
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Useful terms for reading:
- ppm – “parts per million” which is an indication of how much of a substance is present.
- CO₂ – carbon dioxide
- O₂ – oxygen gas

Background
The Earth supports a fragile ecosystem, and its inhabitants depend for their survival upon complex interactions between them, which have developed over billions of years. Imbalance of one component in this bionetwork can have far-reaching effects on organisms whose existence relies upon the presence of other species. Despite the ability to alter their environment in diverse ways, humans are reliant for their survival upon an element derived primarily from plants and produced by chlorophyll during photosynthesis, oxygen (O₂).

Photosynthesis is arguably the single most important chemical process on our planet, and the first colour images captured of Earth from space revealed the vast green hues of the landmasses supporting plant life, confirming its dominance within our ecosystem. Using energy from sunlight, chlorophyll strips electrons from water molecules, which then convert atmospheric carbon dioxide (CO₂) into carbon compounds, producing O₂ as a byproduct. Whilst mechanisms that use alternative naturally available compounds to release energy exist, the abundance of water on the surface of the Earth meant that photosynthesis rapidly became the foremost bio-energetic pathway on the planet. During the early era of chlorophyll
photosynthesis, approximately 2,400 million years ago [1], the atmosphere was rich in CO₂, whilst O₂ was scarce. As time progressed and photosynthetic species slowly overwhelmed the surface of the Earth, the concentration of O₂ rose and eventually reached levels we are accustomed to today.

In the early 1770 s, Joseph Priestley conducted a series of experiments that led to the discovery of the intimate relationship between plant and animal life [2]. In his principal experiment, Priestley placed a mouse within a sealed jar and observed it to eventually perish. When repeated with sprigs of mint within the jar, neither did the animal die ‘nor was it at all inconvenient to a mouse’ [2]. He had made the breakthrough that plants produce a substance which is life-giving to animals and then went on to describe ‘dephlogisticated air’, which, thanks to the French chemist Antoine Lavoisier, soon became known as ‘oxygen’. The story of photosynthesis was completed in 1779 when a Dutchman, Jan Ingenhousz, demonstrated that the process by which plants produce O₂ is dependent upon light.

We hypothesized that a human could survive within a sealed modern-day bell jar, even if the O₂ concentration within was significantly reduced from the outset, provided that it contained sufficient plant matter to generate O₂ and remove CO₂ via photosynthesis.
Results
The concentration of O₂ in the container rose throughout the experiment, peaking at 18.1% in the final hour (hour 48; Figure 2). The CO₂ concentration fluctuated depending on the subject's activity within the container (declining noticeably during sleep), but there was an overall rise that peaked at 0.66%, approximately halfway through the experiment (Figure 3). There was a diurnal variation in temperature (25.3°C to 28.4°C), and humidity varied between 57% and 87%. On entering the hypoxic container, the subject had a heart rate of 90 beats per minute, respiratory rate of 20 breaths per minute and SpO₂ of 86%.
These figures returned to the subject's resting normal values as the concentration of O₂ rose within the container. The subject's final SpO₂ was 99% (Figure 4).
**Discussion**

The design of the biological ecosystem in this study was such that human life was sustained for 48 h and the initial hypoxic environment restored to one of near-normal O₂ concentration. In the early 1990's, the ‘Biosphere 2’ experiment was conducted to explore the feasibility of self-sustaining biospheres in space. This grand design consisted of a 200 m³ atmosphere within a dome that contained eight volunteers, which was designed to sustain them for 2 years [5]. However, the O₂ concentration within the biosphere dropped from 20.9% to 14.2% after 16 months, so additional O₂ had to be added to the atmosphere [6]. This decline was traced to a two-step process: firstly, there was O₂ loss to organic soil matter producing CO₂, and secondly, the CO₂ was being captured by structural concrete to form calcium carbonate [5]. In the current experiment, the initial O₂ concentration of 12.4% (equivalent to approximately 4,500 m above sea level) resulted in a marked reduction in the subject's SpO₂ and represents an acute hypoxic exposure that is frequently associated with symptoms of altitude related illness [7]. During the last few hours of the study, there was a small reduction in rate of the O₂ concentration rise, perhaps due to deterioration in the condition of the plants, noticeable towards the end of the experiment. Direct heating and excessive light exposure, arguably both present in this experiment, can lead to the denaturing of enzymes within chlorophyll [8]. There were fluctuations in CO₂ concentration throughout the study, with a tendency for it to rise as time progressed (Figure 3).

As well as providing an insight into the use of plants to maintain a self-sufficient biosphere, such as would be required on the surface of extraterrestrial bodies without an atmosphere, our experiment highlights the detrimental effects of a markedly increased CO₂ concentration. CO₂ concentrations have altered dramatically over the course of the Earth's history [9], and there is much concern that levels are now rising at an alarming rate [10]. Under certain environmental conditions, increasing the ambient concentration of CO₂ can be beneficial, increasing
photosynthetic activity, plant growth and yield [11,12]. Using CO₂ enrichment to increase plant growth and yield is now commonplace in commercial glasshouse crop production, with optimal levels being between 700 and 1,000 ppm [13]. However, in some species, super-elevated CO₂ concentrations (over 2,000 ppm) induces foliar symptoms of chlorosis and necrosis [14,15], and levels above 10,000 ppm are known to cause damage to young maize plants after 48 h in the form of ‘yellow streaks’ [16]. During this experiment, the CO₂ levels remained above 2,000 ppm and reached a maximum of 6,600 ppm, yet yellow streaks were observed on the maize plants by the end. It is possible that damage to the maize may have also reduced the photosynthetic yield and the production of O₂ towards the end of this experiment. This study, therefore, provides an insight into the use of plants to maintain a self-sufficient biosphere, such as would be required on the surface of extraterrestrial bodies without an atmosphere, and the potentially detrimental effects of a dramatically increased CO₂ concentration.

**Conclusion**

This simple experiment is a humble reminder of the integral relationship between animal and plant life on Earth, in which the former owe their existence to the latter. Without the presence of plants within the sealed environment, the concentration of O₂ would have fallen and CO₂ concentration would have risen to a point at which human life could no longer be supported. Whilst O₂ sustains human life and plants maintain its level within the atmosphere with remarkable efficiency, the fundamental role of photosynthesis is arguably taken for granted. Deprived of plants, the subject within the container would have succumbed to the effects of severe hypoxaemia. The experiment reminds us of our total dependency upon plants, and the ecosystem in which they exist.
References

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