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Moth In Silence:

Unlocking Nature's Stealth Acoustic Camouflage for Sound Absorbing Solutions

Introduction

Scientists have been inspired by nature's secrets and mysteries for millennia. These secrets frequently contain the key to unlocking new inventions and technology that can assist us in resolving some of the most important issues of the day. Researchers at the Royal Society have recently identified and investigated the stealth acoustic camouflage of the Chinese oak silk moth (*Antheraea pernyi*) as one such example. This phenomenon, which enables moths to avoid predators and fly invisibly, might be used to produce sound-absorbing solutions for various enterprises.

Figure 1. Chinese oak silk moth (*Antheraea pernyi*) (Source: Utierweerd, 2014)

Key Scientific Principles

Biology

Many different adaptations to avoid detection have been developed as a result of the arms race between bats and moths (Echolocation, n.d.). One such adaptation is stealth acoustic camouflage, in which moths absorb or disperse sound waves to lessen the amount of sound reflected back to echolocating bats (see Figure 2). Their wings' complex structure, which has evolved to perform multiple functions including flight and acoustic camouflage, is partly responsible for this ability. Researchers have created novel sound-absorbing materials, like noise-canceling wallpapers, that may be used in a variety of contexts to lessen noise pollution by analyzing and simulating the structure and function of moth wings. This is an example of biomimicry, which is the practice of applying natural patterns, systems, and processes to address problems that people encounter (Biomimicry Institute, 2023). In this case, researchers looked into the physical structure of moth wings as a result of evolution to develop creative sound-absorbing solutions to solve challenges in the real world.

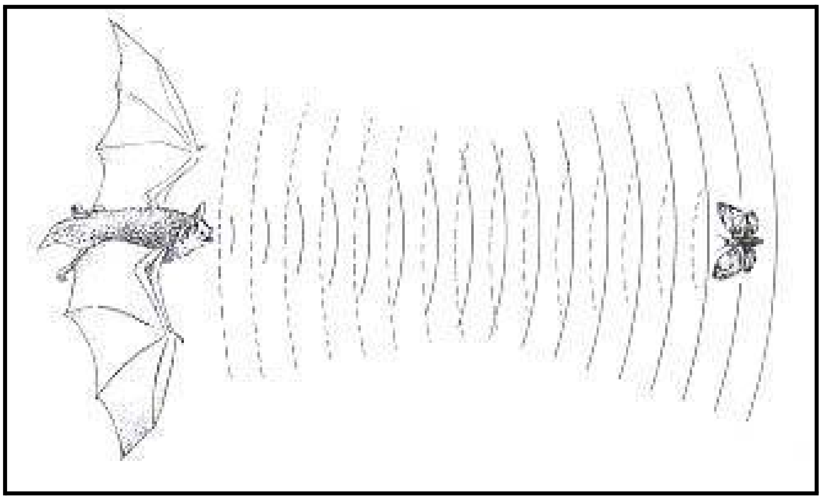

Figure 2. Bat Echolocation (Source: Campbell, 2001)

Physics

Physics also plays a crucial role in understanding the acoustic camouflage of moths. In the form of compressions and rarefactions, sound is a type of mechanical wave that moves through a medium like air or water (Sound is a Pressure Wave, n.d.). Sound waves can be transmitted, reflected, or absorbed when they come into contact with a substance. Moths' bodies and wings have developed unique features that efficiently absorb sound waves, preventing their reflection and lowering background noise. The researchers from the Royal Society discovered that moth wings and bodies efficiently absorb sound waves due to their distinctive structure, texture, and composition, which offers important insights into the mechanics of sound absorption.

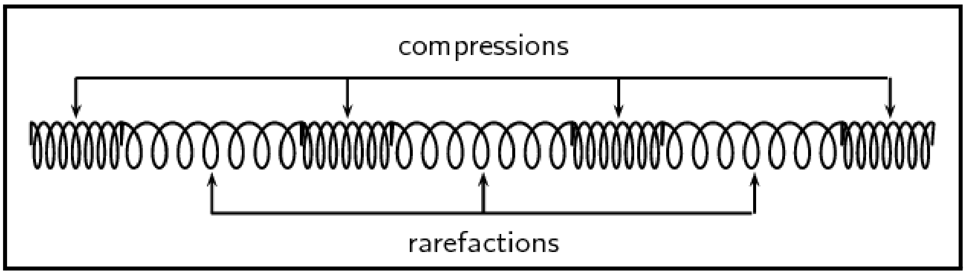

Figure 3. Diagram of Compressions and Rarefactions in a Sound Wave

Chemistry

Another basic scientific idea that contributes to moths' acoustic camouflage is chemistry. The primary substance of moth wings is chitin, a complex carbohydrate. A type of carbohydrate called a complex carbohydrate is made up of long chains of sugar molecules. Chitin is a linear polysaccharide composed of linked N-acetylglucosamine (GlcNAc) residues, which are similar in structure to glucose. The GlcNAc residues are linked by glycosidic bonds, which give the chitin molecule its characteristic rigid and fibrous structure (Gooday, 1990).

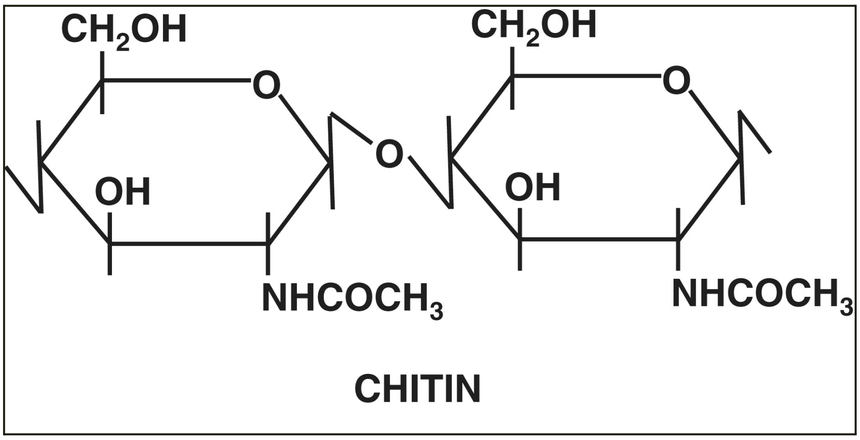

Figure 4. Structure of Chitin

Chitin makes up the majority of the exoskeletons of arthropods, including moths (Rinaudo, 2006). Its distinctive physical makeup provides a material with various beneficial attributes, including lightness, flexibility, and sound absorption. According to the University of Bristol (2021) In order to achieve its sound-absorbing properties, chitin's physical structure is composed of a number of microscopic layers that together form a complex pattern of ridges and valleys on the surface of moth wings. Additionally, moth wings, which are likewise constructed of chitin, include microscopic scales (see Figure 5) that contribute to their sound-absorbing properties. These offer important insights into how chemistry might be used to produce materials with special qualities, such as sound absorption.

Figure 5. False-colour 3D representation of a 0.21 mm x 0.28 mm wing section of the moth *Lasiocampa quercus* showing structure, diversity, and arrangement of base scales (orange) and cover scales (blue and yellow) (Source: University of Bristol, 2021)

Experimental Design

To test their hypothesis about the moth wing structure's acoustic properties, the researchers of the Royal Society (2022) used a combination of experimental and theoretical techniques. Wing scales were imaged using scanning electron microscopy, and scale morphology was characterized by six parameters (see Figure 6). The thickness of the base, ventral, dorsal, and cover scales were measured, and the arrangement of the scales was characterized. The reflection coefficients of the wing samples were measured using sound reflection measurements in an audiometric room, and an aluminum disc was used as a calibration target. The study found that the angular distribution of reflection coefficients was affected by the presence of wing scales and that the thickness and arrangement of scales significantly contributed to the angular dependence of reflection coefficients. The findings suggest that the structure and arrangement of scales play a crucial role in the acoustic properties of insect wings.

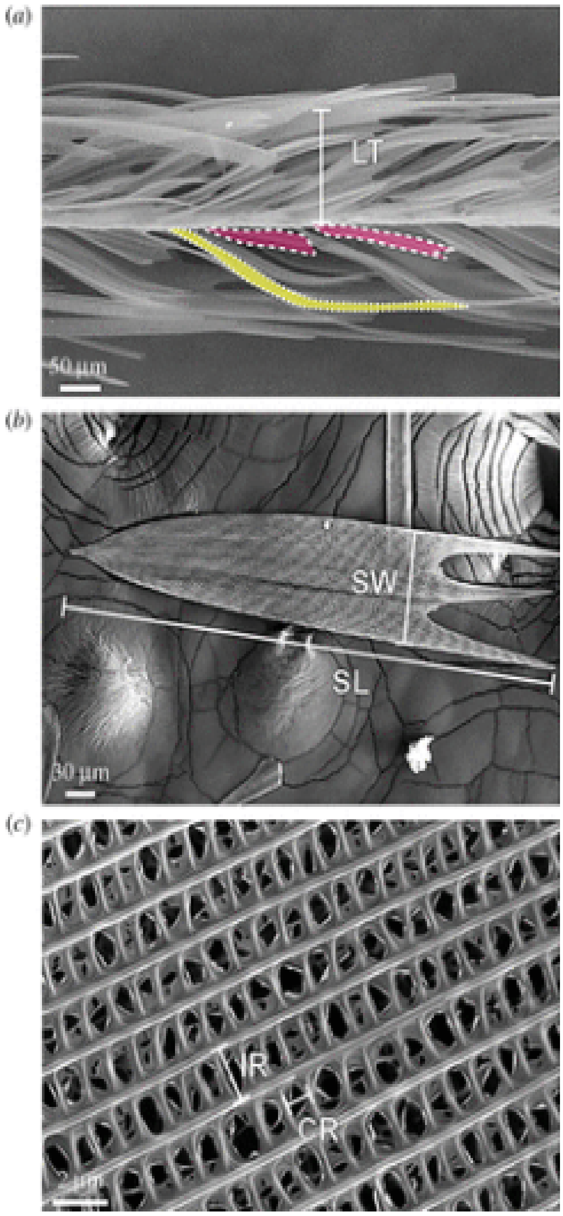

Figure 6. Scanning electron microscopy image of (a) Cross-section through the target wing section highlighting two base scales (pink, white dashed outline) and one cover scale (yellow, white dotted outline). (b) Single base scale in top view. (c) Microstructure of a base scale showing the parallel ridges and cross-ribs. Layer thickness (LT), scale length (SL), scale width (SW), inter-ridge distance (IR) and cross-rib distance (CR). (Online version in color.) (Source: Royal Society, 2022)

Research Findings

The research findings show that a thin natural coating of moth wings, using a thin layer of water to create adhesion, significantly reduces the reflection of acoustic energy from a metal surface at various frequencies. This effect is most pronounced at longer wavelengths, indicating deep-subwavelength performance that is beneficial for architectural acoustics. The reduction in reflection is omnidirectional at low frequencies and becomes more directional as the frequency increases.

The reduction in reflection is mainly attributed to absorption rather than diffusion, as the metal surface used in the experiment is highly reflective. The observed minimum reflection coefficient is lower than previously reported values, indicating high absorption properties of the moth wing coating. The orientation of the coating, specifically whether the dorsal or ventral side of the wing faces the sound, affects the acoustic performance differently. When the dorsal side faces the sound, there is a significant reduction in reflection, while there is little effect when the ventral side faces the sound.

The interaction between the resonating scales and the elastic membrane of the wing coating is believed to be critical in dissipating acoustic energy. The exact mechanism by which the air gap between the wing and the metal surface affects the reflection coefficient is unclear, but it likely involves a reduction in the movement of the membrane due to adhesion to the metal surface, combined with some depth-dependent tuning. The variation in scale morphologies on the wing creates a metamaterial array of tuned resonators, resulting in broadband absorption functionality. These findings have implications for developing novel sound-absorbing materials inspired by natural designs.

Applications

This discovery could potentially result in the development of high-performance soundproofing innovations. Scientists can mimic the sound-absorbing properties of moth wings and create a sustainable and cost-effective alternative to traditional soundproofing materials. They could develop excellent noise-canceling coatings for walls, and vehicles to help reduce the effects of noise pollution and improve passenger comfort.

In architecture, sound-absorbing materials based on the moth wing's acoustic properties could be used to create more effective noise reduction solutions in buildings and public spaces.

In aerospace, the development of stealth materials based on moth wing-inspired designs could make aircraft and vehicles undetectable to radar and sonar systems. This has significant implications for military operations since modern warfare requires stealth technologies (Military Aircraft | Types, History, & Development, 2023*)*.

In audio recording, it can be applied to improve sound quality by reducing unwanted background noise and echo. By incorporating sound-absorbing materials, such as wallpapers, into the design of recording studios or even home recording spaces, the sound waves can be effectively absorbed or scattered, resulting in clearer and higher-quality recordings.

Finally, the utilization of natural, sustainable materials in various applications may result in more environmentally responsible solutions.

Conclusion

The study of moths' acoustic camouflage has revealed novel opportunities for investigation and development in the realm of sound-absorbing materials. We can develop more efficient and environmentally friendly materials with real-world uses in a variety of sectors by understanding the underlying scientific concepts. The Royal Society's investigation illuminates the science underlying this remarkable phenomenon and lays the groundwork for further investigation. We may find even more ground-breaking remedies for issues encountered in everyday life as we continue to unravel the mysteries of nature's acoustic camouflage.

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