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Abstract on potential *Key Experiments* for discussion in the Focus Panel 4: Controlling Biological Functions: Understanding Energy Utilization and Fluctuations in Biological Systems

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Suggestions for experimental work concerning the case study 5.4.4 on the bombardier beetle

A considerable understanding has been gained by Eisner and co-workers (Cornell) and McIntosh and co-workers (Leeds) concerning the nature of the explosive mechanism used in the bombardier beetle.

The unique defence mechanism of the bombardier beetle (Figure 1) squirts a hot spray of water/steam at 100℃ mixed with quinones, on any predators such as ants, frogs, birds. Known for many years by entymologists, this stunning defence mechanism has been brought with fresh vigour to the attention of the scientific community particularly through the pioneering work of Eisner and Aneshansley [1] who found that the spray is formed by a pair of glands which open at the tip of the beetle's abdomen and the photographic evidence [2] in particular demonstrated that the beetle chamber undergoes a series of fast cyclic reactions which heat the water mixture so rapidly that the spray which emanates from the exhaust of this system is not a continuous stream but a series of micro and audible explosions. By rotating the tip of this exhaust located near the abdomen tip, the beetle can aim its weapon in any direction with pin point accuracy in any direction, even has ejecting forward from over the back.

Over a number of years a biomimetic study begun by the University of Leeds has focused on the spray system (Figure 2) of the bombardier beetle and in particular the physics of the remarkable valve system attached to the twin combustion chambers which are of the order of 1mm long. The results of this study [3-8] have exposed an intriguing use that the beetle makes of flash evaporation and boiling where the solution of water mixed with quinones is held under pressure above boiling and then released suddenly by a pressure relief valve. When a rig was built to mimic this at Leeds, it was found that the characteristics of the spray were of great industrial interest and have a wide number of practical applications, including pharmaceutical inhalers, fuel injectors in engines and fire extinguishers [9]. The ejection can be a wide fine spray or can be with a very powerful throw capability both of which in different applications are of great interest.

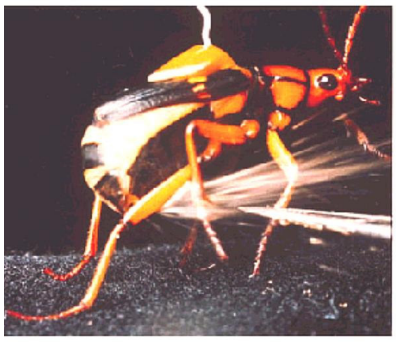

Figure 1. Bombardier beetle in the process of ejecting *(photograph by Eisner)*

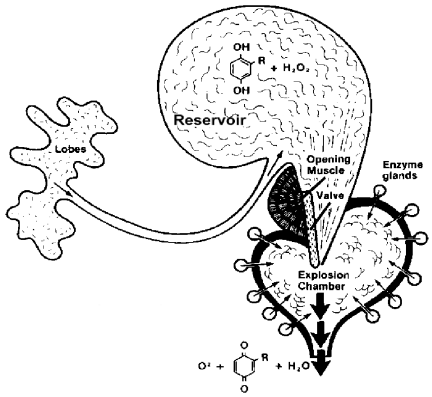

Figure 2. Schematic of the Bombardier beetle discharge apparatus

The bioinspiration from the study of the beetle should not though end with simply the physics of this rather extraordinary design in this small part of the bombardier beetle's anatomy. There are other features which are equally astonishing and have some profound implications for those in search of innovative engineering. There are

(a) material properties of the chamber itself which still need studying in much greater detail to ascertain whether there are peculiar properties of the chamber walls (collagen based) which give great insulation such that the very hot fluid (essentially a water and steam mixture) does not scald the rest of the beetle's anatomy.

(b) There are also issues to do with the tank-like turret at the back of the abdomen of the beetle which can swivel in any direction in all three dimensions. This is of great mechanical interest and could give clues for inspiring novel joint engineering.

(c) The sensing system also needs investigating – how the beetle senses the precise location of its attacker is not yet fully understood (the beetle usually is not facing its attacker – often a bird, a spider, frog or ant) and it usually wins! It is thought that sensory smell organs are probably involved. The response time is exceedingly fast, and it is not yet known whether both of the twin combustion chambers exhaust in tandem or one first, then followed by the other. The catalysts catalase and some peroxidases are reckoned to be attached in crystalline form on the inside hairs of the chamber – this is another area which needs careful investigation as there may be a most useful catalytic application from such features.

(d) Connected with the overall chemistry however perhaps one of the most intriguing matters which awaits a full understanding is the question of the chemical reactant supply before even entering the chamber. Of particular interest is the chemistry of the hydrogen peroxide manufacture used by the beetle.

Diagnostic experiments needed

Some of these questions may be possible to answer if rather than estimates, the actual temperature and pressure of the exhausting fluid during ejection is measured. The author has questions to address to the experimental community concerning whether or not it is feasible to pass x-rays through the spray of the beetle whilst suspended in the process of exhausting (as Eisner by using wax and a hook on the back of the beetle). Is it possible that by analysing the dispersion of the x rays, to then determine the temperature of the ejecting fluid? Is there any way also of measuring the pressure signal from such a small device (the combustion chamber is less than 1mm in length within the beetle which is approximately 1-2 cms. in total length).

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