Investigating the transfer of orbital angular momentum of light to micrometer-sized helical structures

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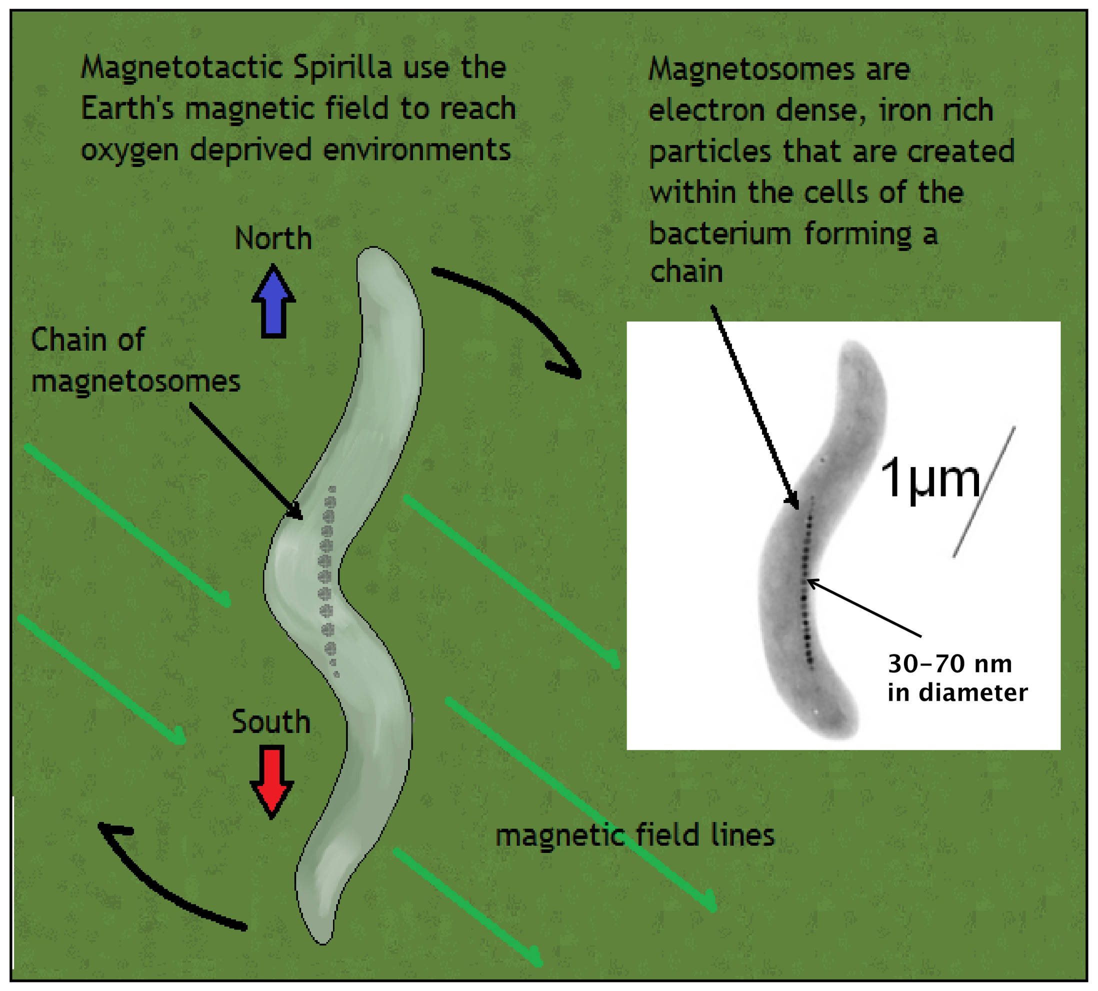
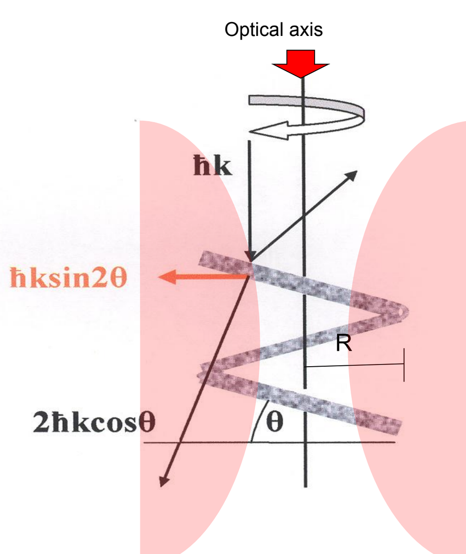
Our Structures: magnetic, helical Bacteria



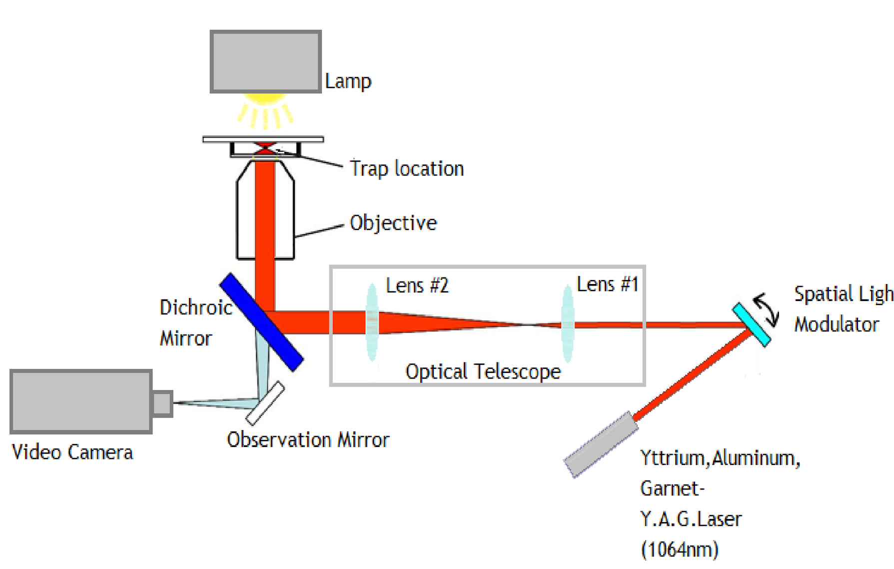
Optical Trapping

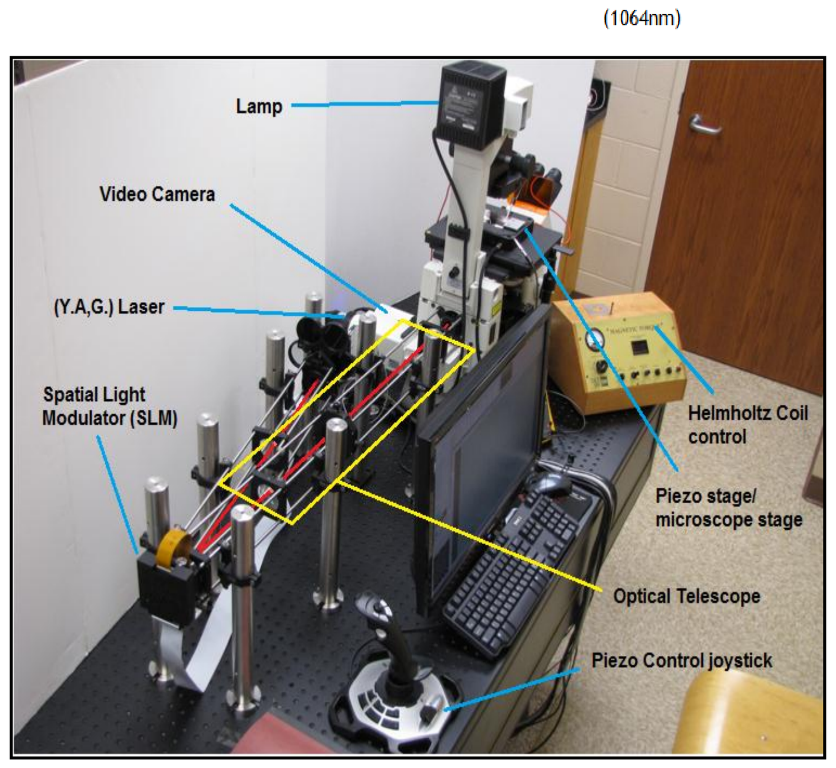
We held our bacteria in optical tweezers which are formed by a tightly focused laser beam:

- A dielectric particle will react to the gradient and scattering force.
- A helical structure rotates in the beam due to momentum transfer from photons



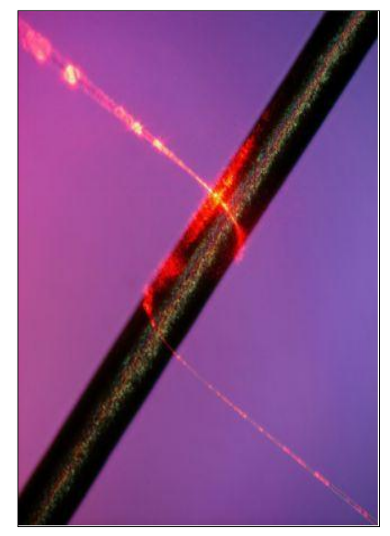
Our Optical Trapping System





Can the magnetosomes be used as nanowires?

- Nanowires are roughly 2000 times thinner than a human hair
- They are being used to make microchip transistors for computing devices and sensor technology. Arrays of nanowires are used to fabricate metamaterials.
- Mainly made of gold



Creating an array of magnetic nanowires

- **What surface do we use to build the array upon? How do we get it to stay in place?**

  We used **Gold Seal® Brand UltraStick™ Adhesion Micro Slides developed by *Cardinal Health*** as a mounting surface.

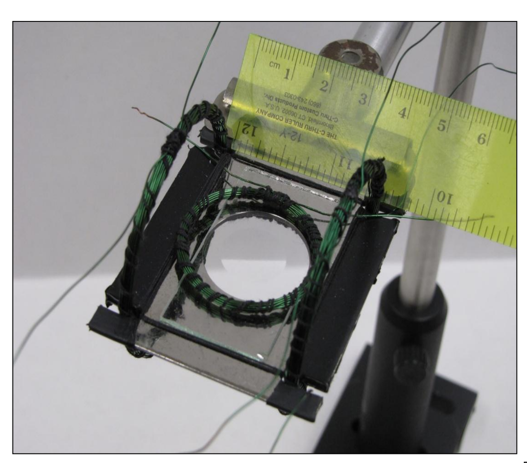
- **How do we know the orientation of the magnetic poles?**

  We fabricated two Helmholtz coil setups that fit on the microscope stage,

  one setup is mounted parallel to the stage allowing for a vertical magnetic field,

  one setup is mounted perpendicular to the stage, allowing for a horizontal magnetic field.

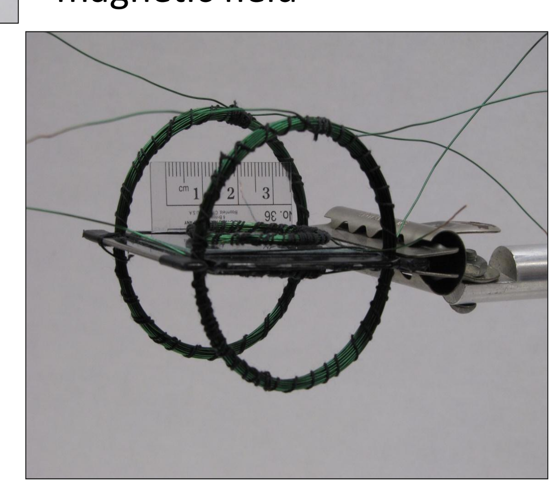
Helmholtz Coil setup



How the coils were made:

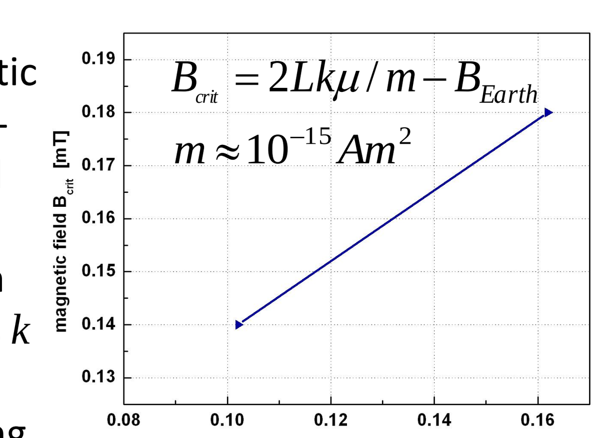
- 22AWG with max current at.92A
- 30 turns per coil
- Producing magnetic field 1.12mT approximately 1000 times greater than the Earth's magnetic field

- The vertical coils have a radius of 25mm
- The horizontal coils have a radius of 12.5mm



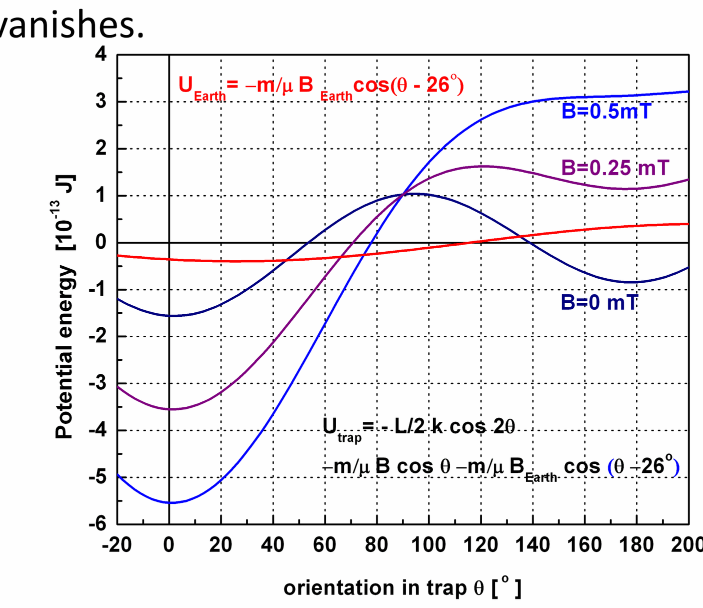
Flipping the bacteria into the desired orientation

An optical trap holds the bacterium (length L, magnetic moment m) in a vertical position. It flips into the desired orientation if the external magnetic field is larger than B_{crit}. Adjusting the strengths k of individual traps allows selecting bacteria for flipping.



Flipping the magnetic Bacteria

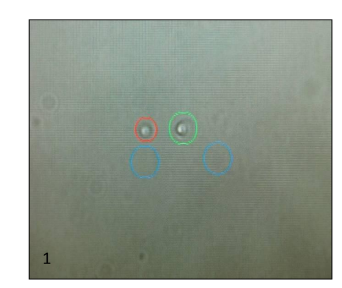
A magnetic bacterium in an optical trap experiences two potential wells if the external magnetic field is weak. When the external field increases, one well gets shallower, the other one deepens. At B_{crit} the second well vanishes.



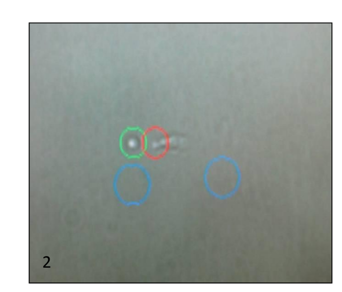
- Potential well of Earth's magnetic field
- Potential wells of the optical trap at 0° and 180°
- With an external magnetic field the potential well becomes deeper at 0° and flattens at 180°
- At B_{crit} the potential well vanishes at 180°. The bacterium flips into 0° orientation

Adhering bacteria to the surface

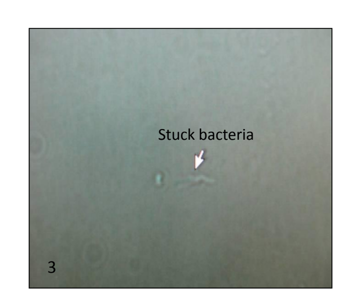
1. We trapped the bacteria, moved the traps in the Z direction and pressed the bacteria gently to the **UltraStick™** slide



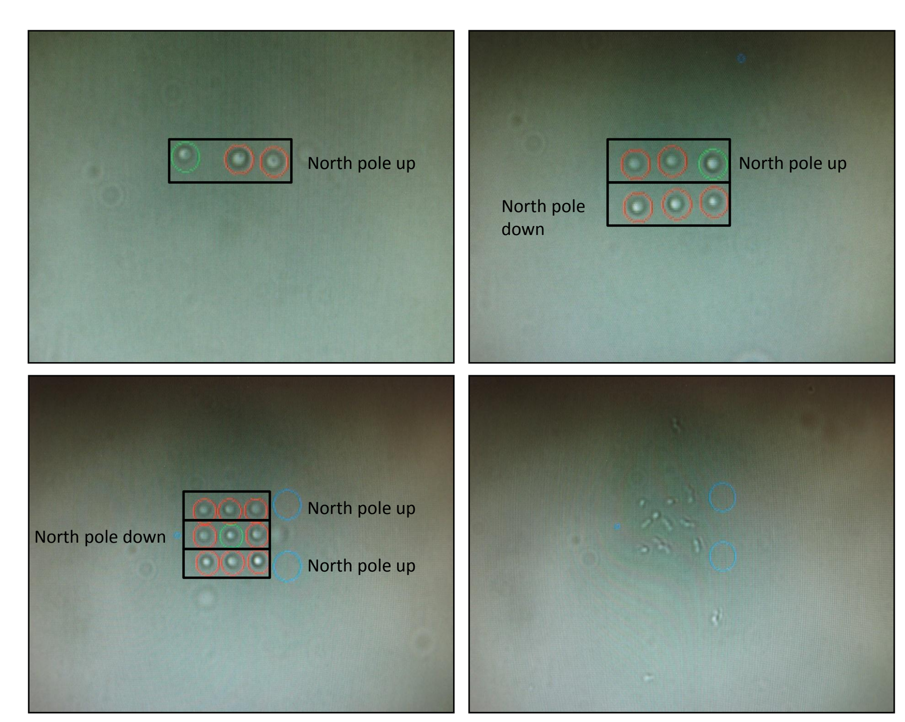
2. Holding the loose end of the bacteria in the trap, the trapped ends were translated along the X-axis, stretching out the bacteria



3. Once stretched, we reversed the magnetic field direction, causing the bacteria to adhere itself to the slide. The bacteria remained stuck after the traps were removed.



Constructing a magnetic array

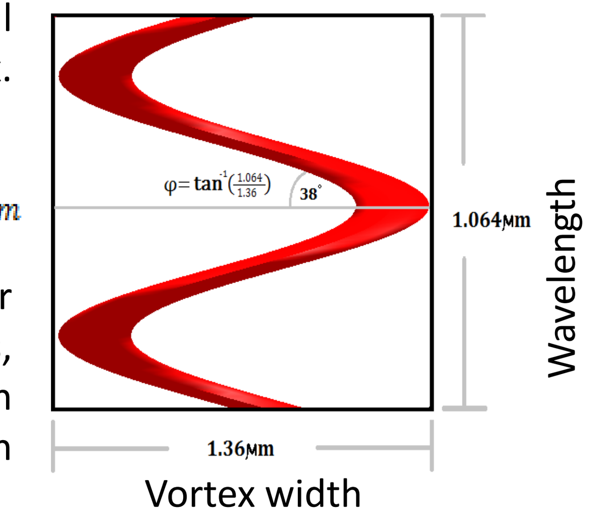


Tweezing with an optical vortex

The electric field in an optical vortex describes a helix. From the radius of the focus

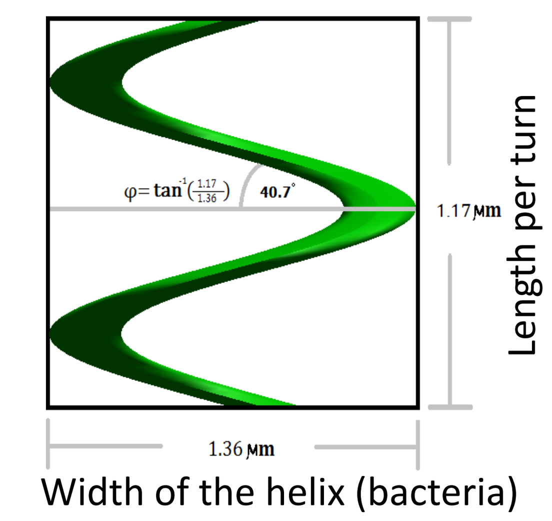
$$q = \frac{1.22\lambda f}{D} = \frac{1.22(1.064\mu m)}{1.9} = .68\,\mu m$$

we find the pitch angle for the electric field ~38°. Thus, the k vectors impinging on the bacteria have a pitch angle of ~52°.



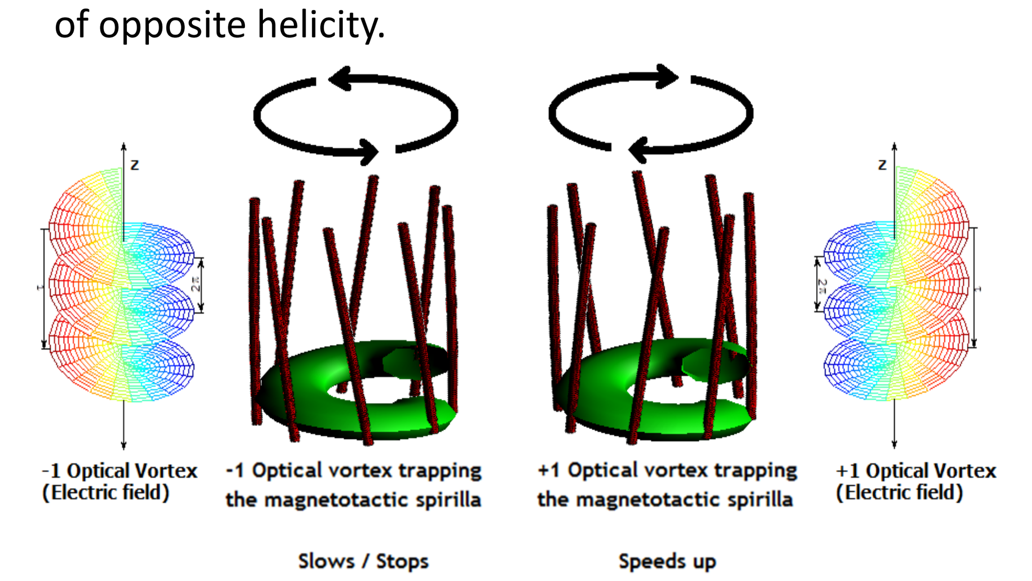
Pitch angle of the bacteria

- We used a sticky slide to pin the bacteria down
- We used calibrated software to measure length and width
- We took the average width and length per turn, to calculate an average pitch angle: ~40.7°



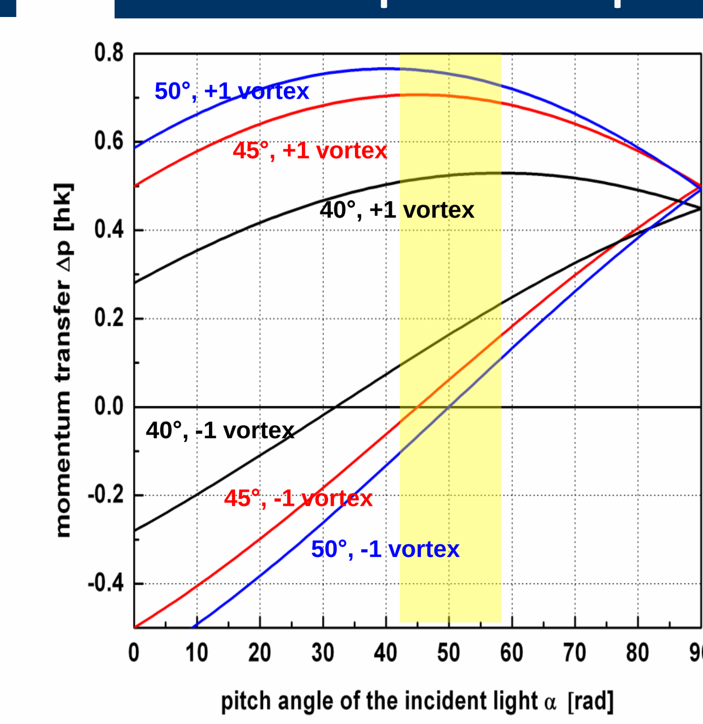
Using optical vortices to trap helical bacteria

Using an optical vortex* that has the same helicity as the bacteria should have a different effect than using a vortex of opposite helicity.



*Created by a computer generated hologram, produced on the Liquid Crystal Display of the Spatial Light Modulator, creating a helical phase shift of the laser beam.

Relationship between pitch and rotational speed



A helical structure with pitch angle ~40° experiences a momentum transfer of ~0.5hk per photon when illuminated with photons of helicity +1 (Black upper graph in yellow area) and ~0.2hk for helicity -1 (Black lower graph). This should lead to a reduced rotational speed of the bacteria.

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