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http://pf.is.mpg.de
3D-printing

MEMS motor

blood cells

cell

bacteria

virus

enzyme

sperm

• 3D nanofabrication
• power at small scales
• microswimming
• biological function
• new devices and actuation …
How can we build something that small?
Life at low Reynolds number

E. M. Purcell

American Journal of Physics, Vol. 45, No. 1, January 1977

If $\mathcal{R} \ll 1$:

Time doesn't matter. The pattern of motion is the same, whether slow or fast, whether forward or backward in time.

The Scallop Theorem
Swimming micro-machine driven by magnetic torque

K. Ishiyama, M. Sendoh, A. Yamazaki, and K. I. Arai,

mm to cm dimensions

Fig. 8. The machine running through the bovine tissue sample.
A team of scientists from Japan have developed tiny spinning screws that can swim along veins.

The screws could then be used to ferry drugs to infected tissues or even burrow into tumours to kill them off with a hot lance.

Kazushi Ishiyama, at Tohuku University, in Japan, designed his swimming micromachines based on cylindrical magnets, just eight millimetres long and less than a millimetre in diameter.

Because the spinning devices are so small Mr Ishiyama believes they could be injected into the body using standard hypodermic needles.

Once inside they could then be steered round the body magnetically, carrying drugs to the site of infection.
biomedical MicroBots

Stimulation/ measurement in brain

Drug delivery in eye

Flow measurement in lymphatic system
Micro- and Nanorobots

1. Nanofabrication in 3D
2. Bio-inspired Microbots
3. NanoBots penetrate tissues
4. Autonomous motion: chemical motors
5. A micro-scallop swimmer
Nanopropeller

A.G. Mark, J. Gibbs, T.-C. Lee, P. Fischer
*Nature Materials* 12, 802 (2013)

D. Schamel, A. Mark, J.G. Gibbs, C. Miksch, K. Morozov, A. Leshansky, P. Fischer,
*ACS Nano* 8, 8794 (2014)
How to realize a MicroBot?
Glancing angle deposition (GLAD)


micropropellers

\[ \vec{\tau} = \vec{m} \times \vec{B} \]
magnetically actuated micropropellers


Micro-propellers in vitreous

Micro-propellers
~0.04 µm/s

Debora Schamel
biomedical MicroBots

Stimulation/measurement in brain

Drug delivery in eye

Flow measurement in lymphatic system

http://www.wisegeek.com/what-are-lymphatic-vessels.htm

http://commons.wikimedia.org/wiki/Template:Human_body_diagrams

http://www.emedicinehealth.com


http://commons.wikimedia.org/wiki/Template:Human_body_diagrams

Hyaluronic Acid

Collagen type II fibrils


Cellia et al. PNAS, 2009, 106: 14321-6
Active pulling of magnetic nanoparticles through vitreous

$$\vec{F} = \left( V/\mu_0 \right) \Delta \chi (\vec{B} \cdot \vec{\nabla}) \vec{B}$$

Magnetic force

Tian Qiu
Average velocities of different diameter beads in porcine vitreous

Tian Qiu

< 500 nm

(force 20 pN)
Nano-barcodes ($C_{\infty v}$)  
Nano-zigzags ($C_s$)  
Nano-hooks ($C_1$)
the world’s smallest screw propellers

Smallest nanopropller in solution to date (300 nm)

Quantum-dot fluorescent labelling
Hyaluronic Acid Solutions

5 mg/ml hundreds of cP

Schamel et al., ACS Nano 8, 8794 (2014)
Nanopropellers in viscoelastic media
Three-dimensional optical printing
Direct laser writing of p-n junctions
Molecular motors

Block lab, Stanford
walk on tracks

Minimum size for useful locomotion by free-swimming microbes > 800 nm

Dusenbery, PNAS 1997
Chemically powered microdrills

self-phoretic colloid

\[ \nabla n \]

self-propulsion

\[ v_{\text{slip}} = \mu_{\text{mobility}} \nabla_{\parallel} n \]
autonomously powered microdrills

Microscallop
reciprocal motion microswimmer


Nature Communications 5, 5119 (2014)
physicist’s scallop

reciprocal motion

...A-B-A-B-A-B-A....
biological fluids

Flow measurement in lymphatic system

Stimulation/ measurement in brain

viscoelastic non-Newtonian (inhomogeneous)

http://www.wisegeek.com/what-are-lymphatic-vessels.htm


http://commons.wikimedia.org/wiki/Template:Human_body_diagrams


Cellia et al. PNAS, 2009, 106: 14321-6
non-Newtonian fluid

shear thinning fluid: hyaluronic acid (6 mg/ml)

\[ \mu = 3.35 \gamma^{0.60-1} \]
Fabrication via a photolithographically fabricated mold
Micro-scallop swims while falling under gravity

Helmholtz coil to drive the micro-scallop in a large tank

Micro-scallop is made of PDMS

*Nature Communications* 5, Article number: 5119 (2014)
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Thank you for your attention!