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A review of optically induced rotation

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Key words: Optical tweezer; Optically induced rotation; Angular momentum; Micro-rotor

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Motivation

- For decades, optical rotation techniques have been widely applied in laboratory optical manipulation and several diverse areas, such as biophysics, nanotechnology, microrheology, microfluidics, and chiral resolution.
- With the latest breakthrough in cooling technique and the development of quantum optomechanics, optically induced rotation has rapidly become a vital instrument in microscopic particle manipulation and torque measurement.
- In this review, we introduce the development history and recent advances of optical rotation techniques. The potential of optical rotation techniques encourages researchers to continue exploration.

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Contents

- Introduction of pioneering exploration of angular momentum, including orbital angular momentum and spin angular momentum
- Details of the application of optical rotation caused by spin angular momentum in liquid medium
- Details of the application of optical rotation caused by orbital angular momentum in liquid medium
- Elaboration of the progress of optical rotation techniques in high vacuum and analysis of the prospect of ultra-fast micro-rotor in optical tweezers

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Optical rotation techniques

- Orbital angular momentum (OAM)
- Spin angular momentum (SAM)
- Other methods

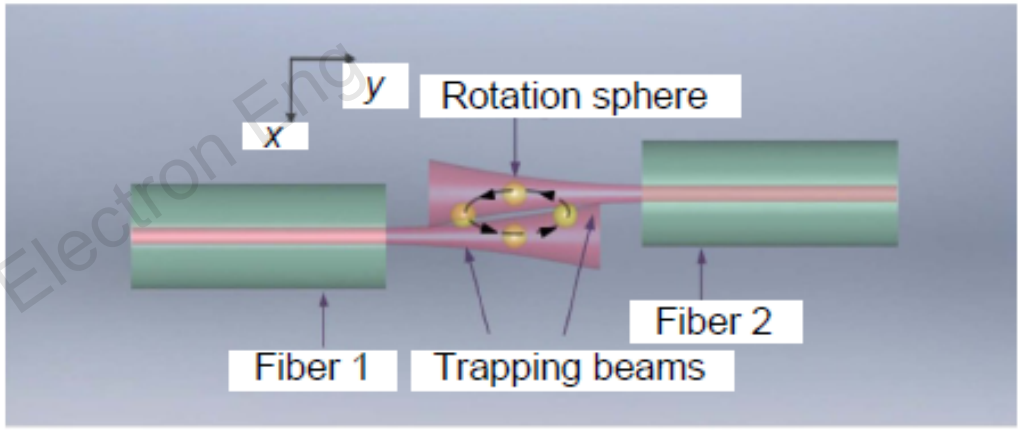


Fig. 1 Rotating particle by misalignment along the radial axis

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Li WQ, Li N, Shen Y, et al., 2018. Dynamic analysis and rotation experiment of an optical-trapped microsphere in air. *Appl Opt*, 57(4):823-828. https://doi.org/10.1364/AO.57.000823

Applications of optical rotation techniques

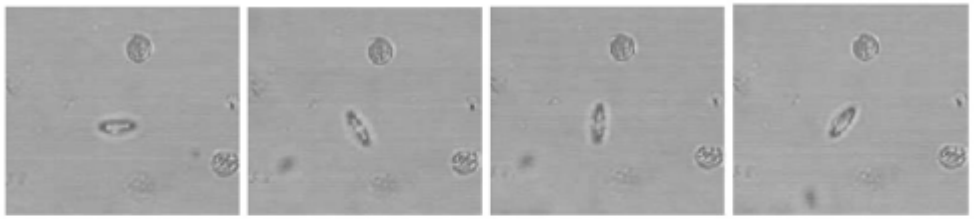


Fig. 2 Alignment of chloroplasts with linearly polarized laser beam

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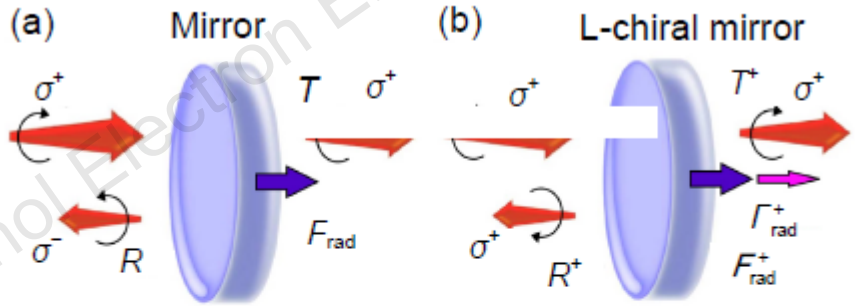


Fig. 3 Principle of chiral selection: (a) a traditional mirror with reflectance *R* experiences only a radiation force; (b) a left-handed chiral mirror experiences a radiation force and a torque

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Bayoudh S, Nieminen TA, Heckenberg NR, et al., 2003. Orientation of biological cells using plane-polarized Gaussian beam optical tweezers. *J Mod Opt*, 50(10):1581-1590. https://doi.org/10.1080/09500340308235232

Donato MG, Hernandez J, Mazzulla A, et al., 2014. Polarization-dependent optomechanics mediated by chiral microresonators. *Nat Commun*, 5:3656. https://doi.org/10.1038/ncomms4656

Applications of optical rotation techniques

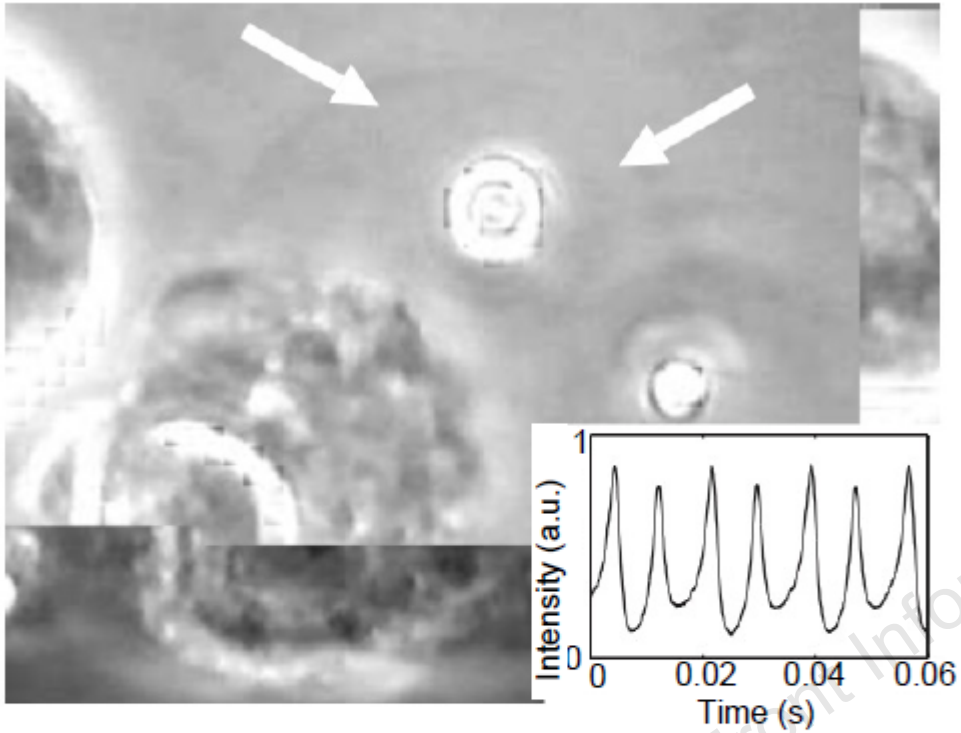


Fig. 4 A phase-contrast image of a vaterite rotating inside a cell as a microviscometer

The left arrow points to the cell membrane. The right arrow points to the vaterite within the cell membrane. The inset picture shows the normalized intensity that is used to determine the rotation rate of the vaterite. Reprinted from Parkin et al. (2007), Copyright 2007, with permission from American Physical Society

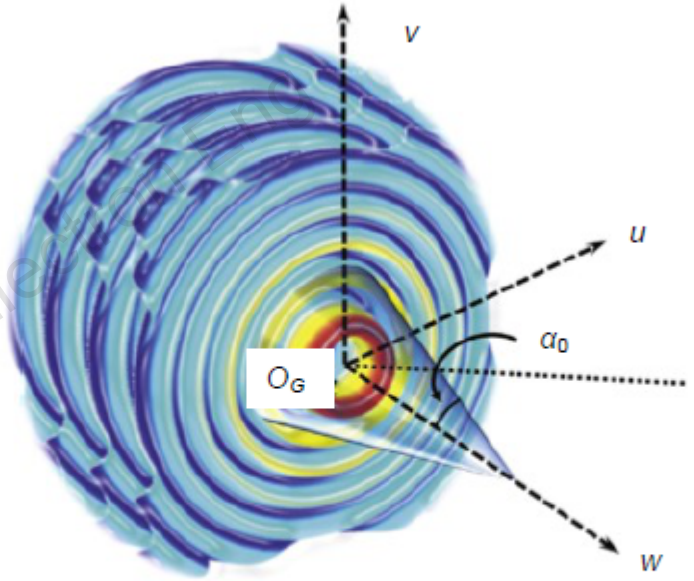


Fig. 5 Wavefront of Bessel beam

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Li RX, Yang RP, Ding CY, et al., 2017a. Optical torque on a magneto-dielectric Rayleigh absorptive sphere by a vector Bessel (vortex) beam. *J Quant Spectrosc Radiat Trans*, 191:96-115. https://doi.org/10.1016/j.jqsrt.2017.02.003

Parkin SJ, Knöner G, Nieminen TA, et al., 2007. Picoliter viscometry using optically rotated particles. *Phys Rev E*, 76(4):041507. https://doi.org/10.1103/PhysRevE.76.041507

Optical rotation techniques in high vacuum

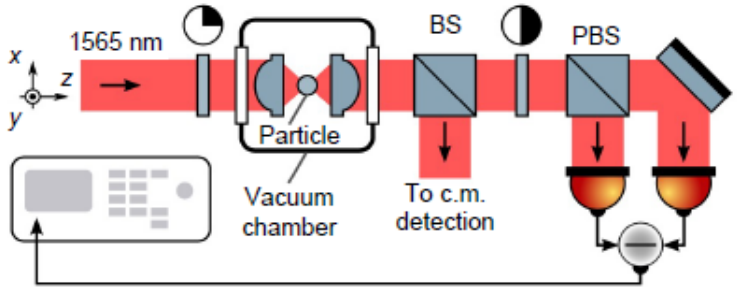


Fig. 6 Experimental setup in Reimann et al. (2018)'s research

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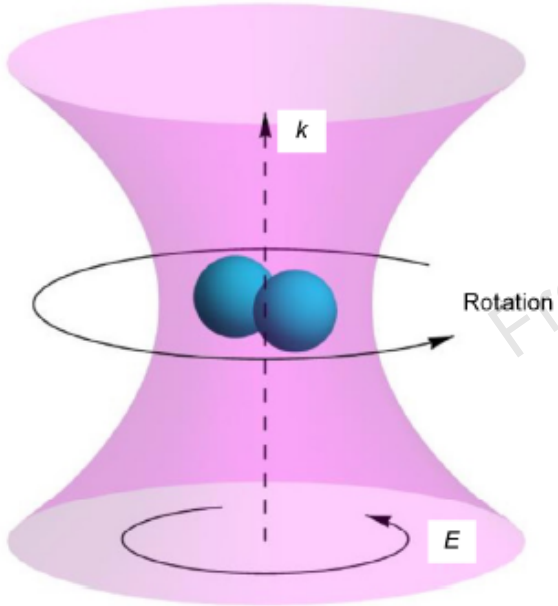


Fig. 7 Scheme of a nano-dumbbell rotating in optical tweezers

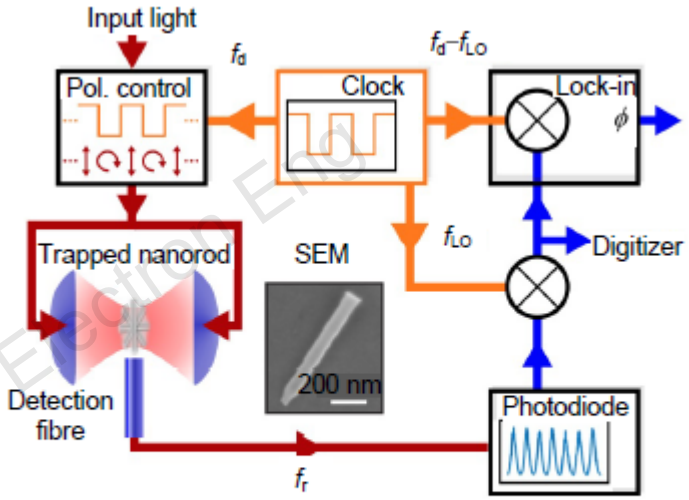


Fig. 8 Scheme of frequency locking experiment

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Reimann R, Doderer M, Hebestreit E, et al., 2018. GHz rotation of an optically trapped nanoparticle in vacuum. *Phys Rev Lett*, 121(3):033602. https://doi.org/10.1103/PhysRevLett.121.033602

Ahn J, Xu ZJ, Bang J, et al., 2018. Optically levitated nanodumbbell torsion balance and GHz nanomechanical rotor. *Phys Rev Lett*, 121(3):033603. https://doi.org/10.1103/PhysRevLett.121.033603

Kuhn S, Stickler BA, Kosloff A, et al., 2017b. Optically driven ultra-stable nanomechanical rotor. *Nat Commun*, 8(1):1670. https://doi.org/10.1038/s41467-017-01902-9

Development of optical rotation

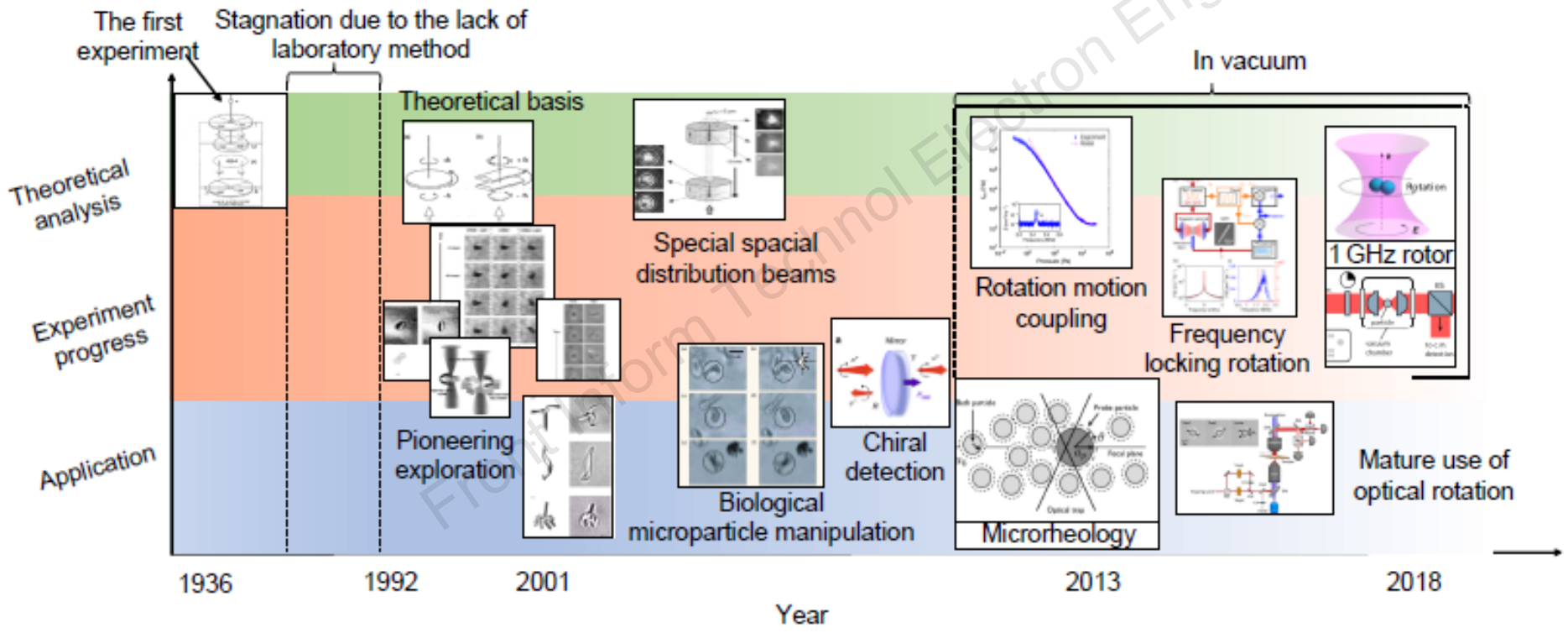


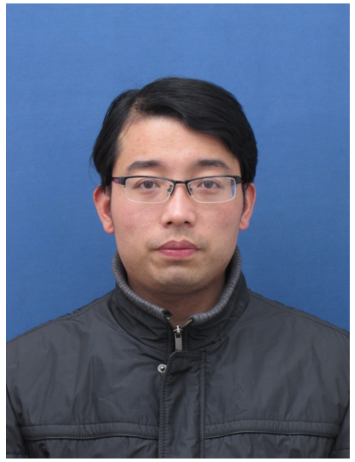
Fig. 9 Development history of optical rotation

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Conclusions

- The techniques of trapping and manipulating particles have made significant progress since first proposed.
- Controllable rotation and precise alignment have made optical trap the most suitable tool for manipulating biological cells and obtaining liquid character.
- Owing to the successful trapping of a particle in high vacuum with optical tweezers, the optically induced rotation had entered into a brand-new phase. With extremely low drag force, the rotation rate has increased dramatically.
- In this review, we explored the development process of optical rotation. Experiments and multiple methods to impart rotating motion on trapped particles and applications of such techniques were introduced.

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