Worksheet 2:

How do optical tweezers work?

Today, the ability to grip, position, and move small particles like bacteria, cells, or cell components with laser beams plays an important role in biological and medical research. The foundations of these optical instruments were laid by the experimental physicist **Arthur Ashkin** in the early 1970s. He was awarded the Nobel Prize for Physics in 2018 for his groundbreaking research.

Exercises:

1. The following video and informative poster briefly explain how lasers work and give an overview of Arthur Ashkin's fundamental ideas.

a) Watch the video "Light and optics V: light as a modern scientific tool (2019)" as an ideal introduction to the topic: www.mediatheque.lindau-nobel.org/videos/38188/light-and-optics-v-de.

b) The poster "Tools made of light" about the 2018 Nobel Prize in Physics is also worth reading: www.kva.se/en/publicerat/nobelpriset-i-fysik-2018-nobelaffisch.

2. In the first worksheet, you learned that photons reflected from a surface can transfer momentum to a body. But a transfer of momentum also occurs when a light beam penetrates into a transparent body and is refracted. Specifically, the direction of the momentum changes at the interface with the second medium, and this changes the momentum of the transparent body in accordance with the law of conservation of momentum. For this to happen, the laser beam needs to be strongly focused, and the particles we want to trap need to be transparent and optically denser than the surrounding medium.

Refraction and the associated change of direction of the photons result in momentum vectors that always push the particle towards the focus of the laser beam. This creates an optical trap that you can use to position and hold transparent particles. The beam of light acts like contactless pliers. This is why the instrument is often called **"optical tweezers"**.

The illustration to the right explains how these **"light grippers"** work, with some simplifications. You can see how strongly focused laser light affects a small, spherical particle.

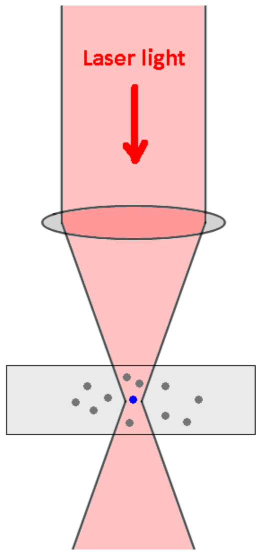


Image source: M. Borchardt

To understand the effect of light refraction on the body, two rays of light are selected from the laser beam and traced out individually below. Drawing the light paths makes it easier to see how the direction of the momentum of the incoming photons is changed by refraction in the optically denser medium. This creates a change of momentum $\Delta\vec{p}$. On account of the conservation of momentum, the other body in the collision also experiences a change of momentum, transferring momentum $-\Delta\vec{p}$ to the particle. The graph shows that, overall, the momentum is directed upwards – the particle is pushed towards the focus.

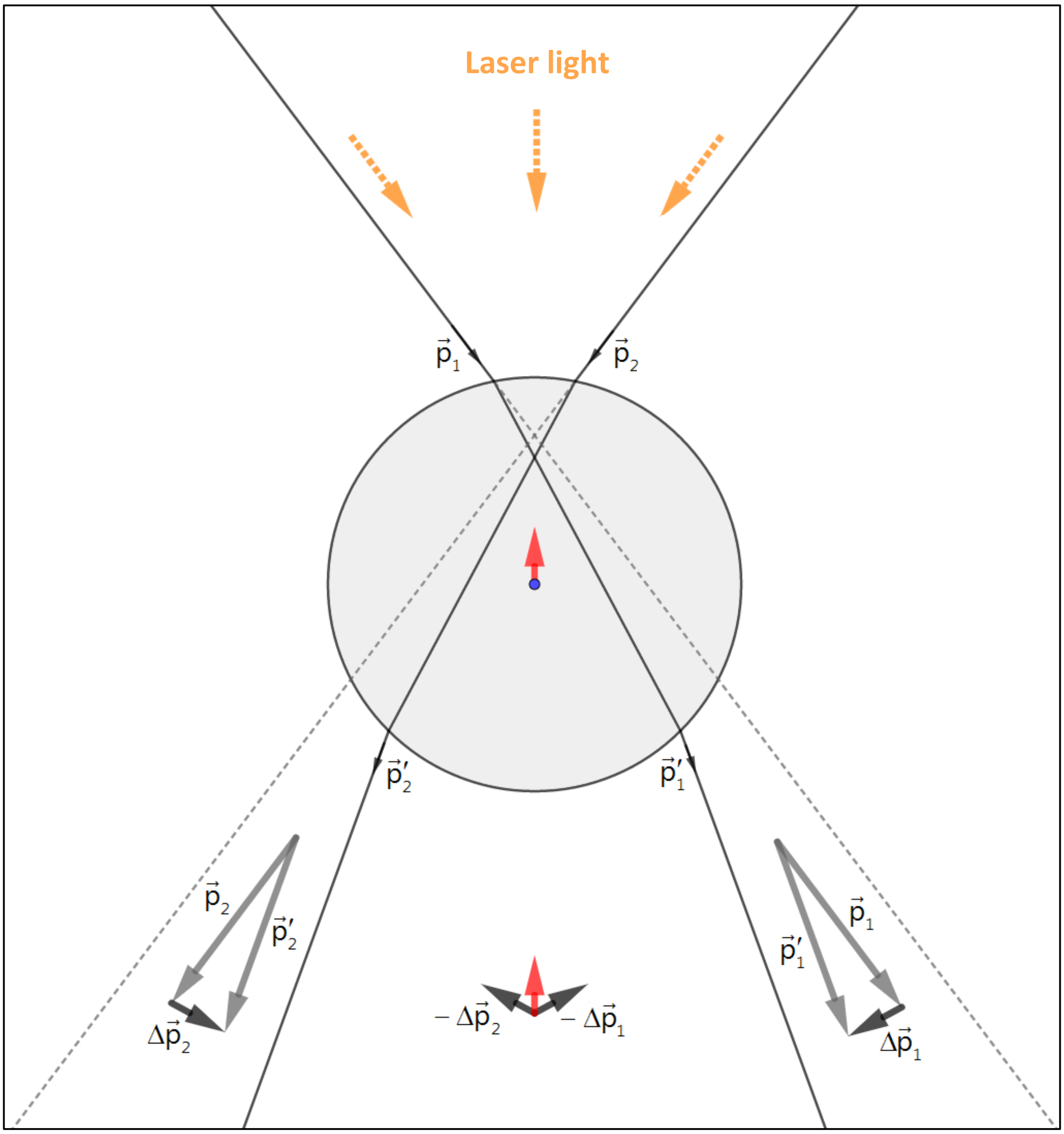
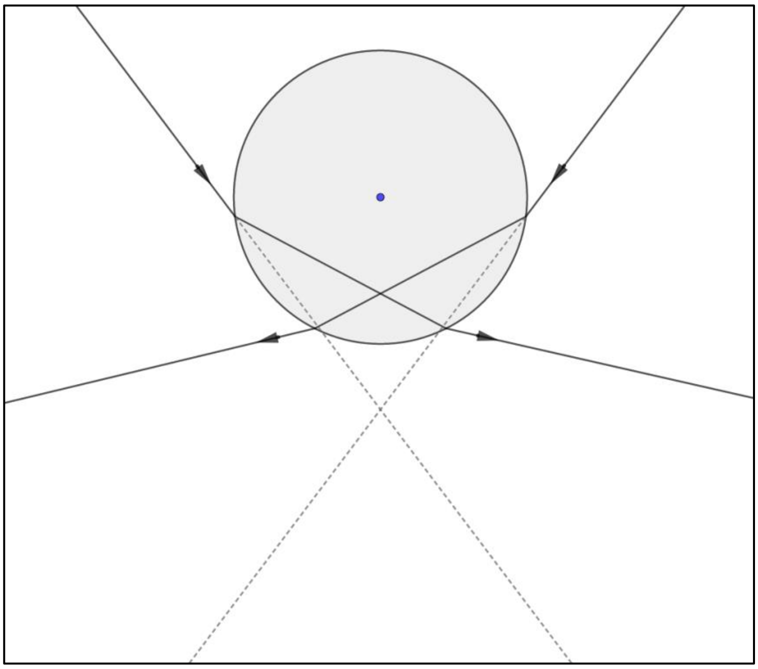


Image source: M. Borchardt

The following two figures show other situations where the particle isn't lined up with the focus of the light beam – one where the particle is quite far above it, and another where the particle is slightly to the right of the focus. In both cases, the light creates a force directed towards the focus.

Determine the momentum graphically as in the above figure and show that each spherical particle experiences a force directed towards the focus of the laser beam.



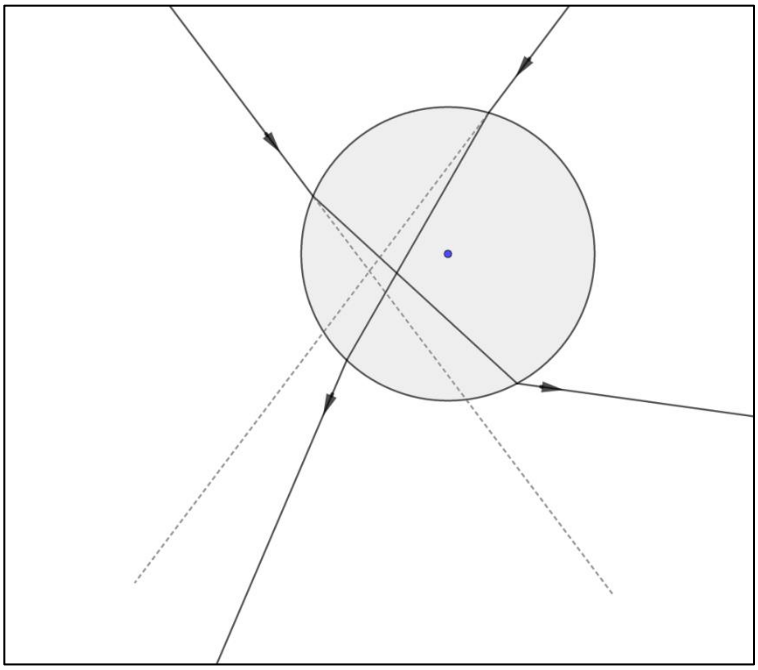


Image source: M. Borchardt

