# Quantum Optical Magnetometry for Biomedical Applications

Kasper Jensen[1,*], Hans Christian Stærkind[1], Jens Arnbak[1], Bo Hjorth Bentzen[2], Eugene S. Polzik[1]

[1] Niels Bohr Institute, University of Copenhagen, Blegdamsvej 17, 2100 Copenhagen, Denmark.
[2] Department of Biomedical Sciences, University of Copenhagen, Blegdamsvej 3, 2200 Copenhagen N, Denmark.
[*]kjensen@nbi.dk

## Biomagnetometry

Electrical measurements are today widely used in medicine for diagnostics purposes. The advent of highly sensitive magnetometers in the last 50 years has opened the field of bio-magnetometry, where the ionic currents inside living organisms are mapped by measuring the small magnetic fields that they generate. The great advantage of a magnetic probe, compared to an electrical probe, is that it doesn't have to be in direct contact with what it is measuring on. The field has been pioneered by superconducting quantum interference device (SQUID) magnetometers. But these have the major drawback of only working at *cryogenic temperatures*.

## Our quantum optical cesium magnetometer

Our optical magnetometer consists of a *room-temperature* cesium vapor cell which is coated on the inside with paraffin. By optical pumping, the cesium atoms are polarized along the direction of an applied static magnetic field. Any bio-magnetic field which is present will drive the atomic polarization away from this direction. The atomic polarization, and thereby the bio-magnetic field, is measured using the Faraday rotation of the light polarization of a probing laser. Our magnetometer has high sensitivity which enables us to detect tiny biological signals. The sensitivity of our optical cesium magnetometer is mainly limited by quantum noise originating from the Heisenberg uncertainty principle of Quantum Mechanics.

## Detection of nerve impulses

We have detected animal nerve impulses with our miniature cesium magnetometer [1]. The nerve is stimulated electrically in one end, which triggers an action potential that propagates to the other end. We demonstrate that our magnetometer is capable of detecting the magnetic field from the nerve impulse at several mm distance (Fig. 1), corresponding to the distance between the skin and nerves in medical studies. Possible applications of our magnetometer include diagnostics of multiple sclerosis, myotonia and intoxication in patients.

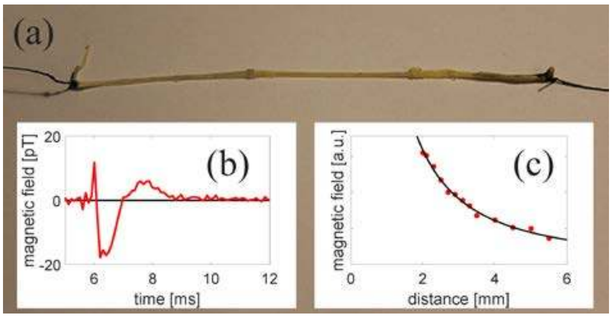


*Figure 1: (a) Frog sciatic nerve. (b) Magnetic field from a nerve impulse. (c) Magnetic field as a function of distance from the nerve.*

## Detection of the heartbeat

We have also measured the magnetocardiogram (MCG) of an isolated guinea-pig heart (Fig. 2). We can resolve the P, QRS and T features consistent with what is seen in a standard electrocardiogram (ECG). Possible applications of our technology include non-invasive detection of the fetal heartbeat (fetal-MCG).

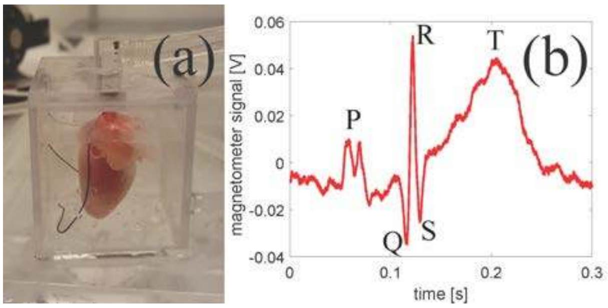


*Figure 2: (a) Isolated guinea-pig heart. The heart is perfused with water containing oxygen such that the heart can be kept a live and beating for > 3 hours. (b) Magnetic field from the heart.*

[1] K. Jensen et al., *Non-invasive Detection of Animal Nerve Impulses with an Atomic Magnetometer Operating Near Quantum Limited Sensitivity.* Scientific Reports **6**, 29638 (2016).