
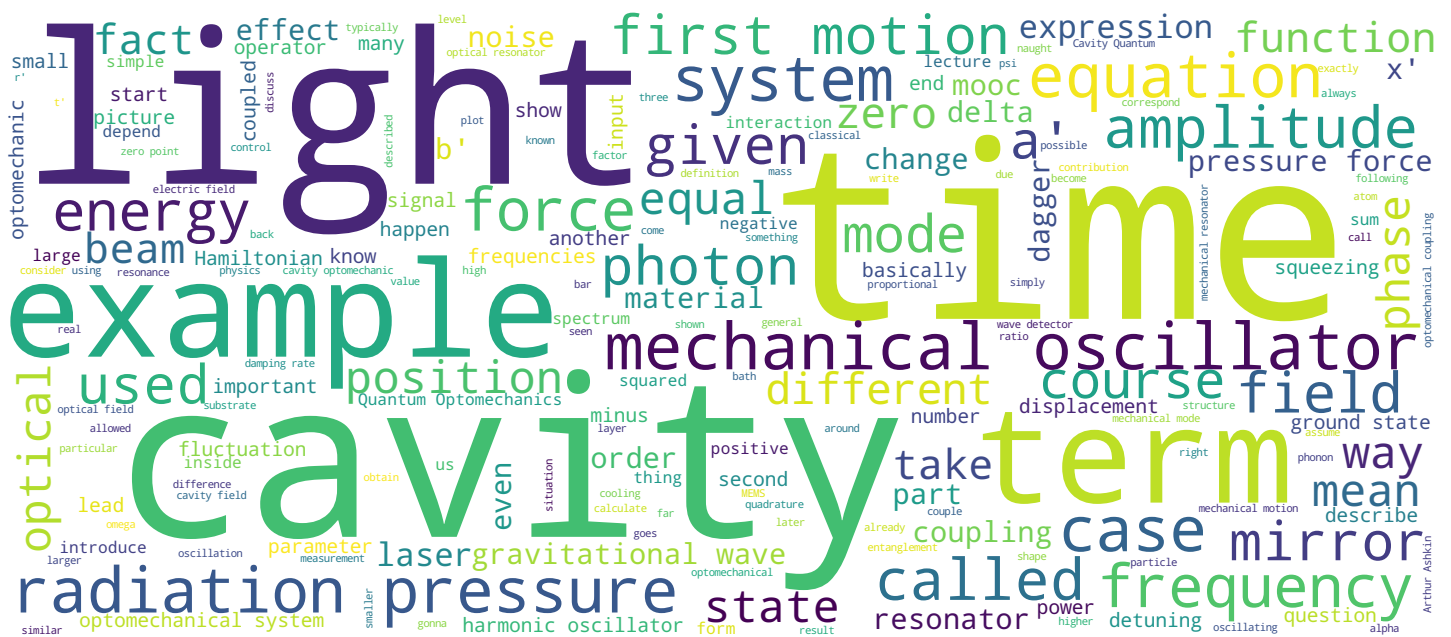


Welcome to

Cavity Quantum Optomechanics



OPTOMECHANICAL
TECHNOLOGIES



Search MOOC

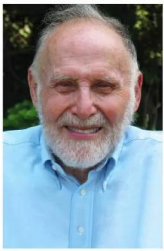
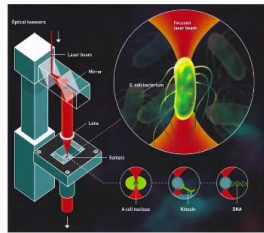
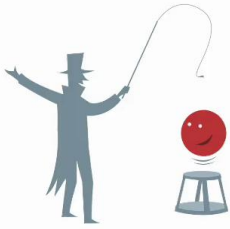


Video



EPFL

QUANTUM CONTROL OF ATOMS AND IONS USING LASERS



Arthur Ashkin

Welcome. My name is Tobias Kippenberg. I'm in the institute of Physics at the Swiss Federal Institute of Technology EPFL, Lausanne, and I have a pleasure to you to introduce you to today the mooc on Cavity Quantum Optomechanics. This mooc was put together by us and us is a network of scientists that have worked under the Optomechanical Technologies, OMT network which is the Marie Curie Training Network sponsored by European Commission and within the framework of this program we have put together a mooc that allows you, interested students, researchers or any person that interested in this subject to explore what Cavity Quantum Optomechanics is about. What is Cavity Quantum Optomechanics? The quantum control of atoms, ions and molecules using radiation pressure of lasers is a technology that has been first pioneered by Arthur Ashkin in early 70s who observed the radiation pressure, the forces that light exert, can be used to manipulate particles. In early work, Arthur Ashkin trapped bacteria and later on with worker Steven Chu, developed techniques to cool atoms to almost complete standstill.

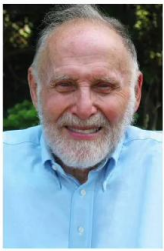
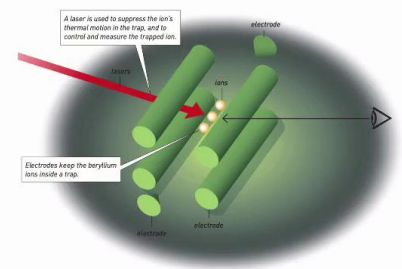
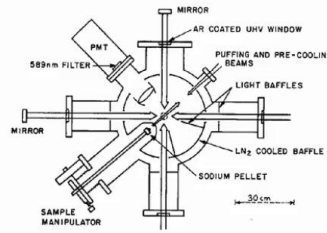
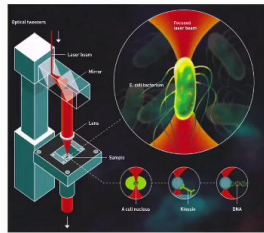
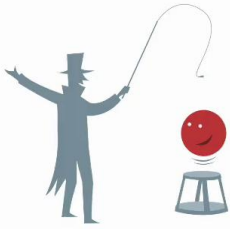
Notes

Summary



0m 00s

QUANTUM CONTROL OF ATOMS AND IONS USING LASERS



Arthur Ashkin



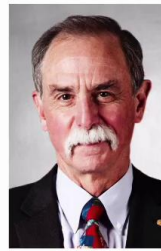
Claude Cohen-Tannoudji



Steven Chu



William D. Phillips



David J. Wineland



NobelPrize.org

The pioneering work of Steven Chu, Arthur Ashkin, Claude Cohen-Tannoudji and Will Phillips laid the revolution for atomic laser cooling for achieving ultra-cold temperature of cold atomic clouds that manipulated using the radiation pressure of light. Such research had brought forward completely new states of matter such as Bose-Einstein condensation, have led to a new and very precise optical atomic clocks and generally have allowed us to explore the quantum properties of individual atoms. Today atoms and ions can be manipulated at a quantum level using the pioneering techniques of Arthur Ashkin and others late in the 70s. Okay. A One example. Some of the most precise clocks that exist today that are based on laser-cool trapped ions which have a greater precision whereby even small shifts in the gravitational potential of less than one meter, okay, can be discernible, okay, in differences in the atomic clock in account to make up our frequencies. Now one question that has arised and been an enduring challenge in the fields of quantum optics that connects matter like is the question if one can also extend the accurate control that lasers have allowed to access over atoms, ions and molecules also over macroscopic mechanical oscillators.

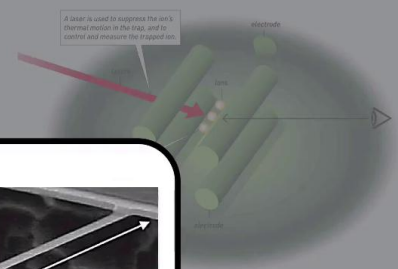
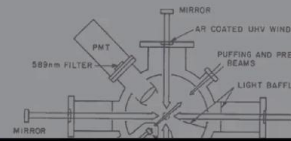
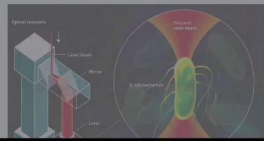
Notes

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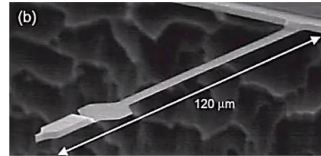


1m 09s

CONTROLLING THE MOTION USING LIGHT



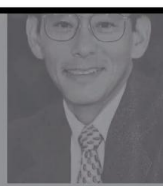
CAN OPTICAL QUANTUM CONTROL BE EXTENDED TO NEMS / MEMS?



Arthur Ashkin



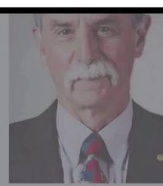
Claude Cohen-Tannoudji



Steven Chu



William D. Phillips



David J. Wineland



NobelPrize.org

Can optical quantum systems also be controlled at the quantum level? So can we extend these controls to so-called NEMS and MEMS, which stands for Nanoelectromechanical Systems or MEMS which are Microelectromechanical Systems. And NEMS and MEMS are a part of our daily life.

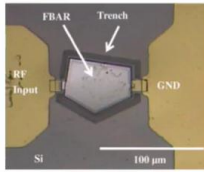
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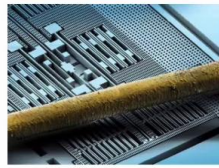
2m 28s

MECHANICAL OSCILLATORS IN SCIENCE AND TECHNOLOGY



FBAR filters

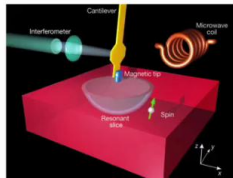
R. Ruby et al., /SSCC, pp120-121 (2001)



Accelerometers



Timing

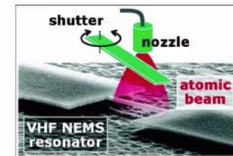


Force sensing

Mechanical Oscillators

Advantages:

- speed of sound $\ll c$
- High Q



Mass sensing

Gravitational Wave Detection



Mechanical oscillators are ubiquitous in science and technology and examples include FBAR filters, which are used in cell phones or by the mechanical oscillator. In this case it's a piezo mechanical oscillator allowed and used to filter the RF radio frequencies we used in our cell phones for communication. Mechanical oscillators are also part of accelerometers or used as quartz tuning forks in timing that is in quartz watches. But also mechanical oscillators are used in some of the most sensitive experiments that human mankind have undertaken such as modern gravitational wave detectors which have allowed in 2018 to detect for the first time the merger of gravitational wave, merger of black holes that allowed the dark observation of gravitational waves. Now in all these applications be the classical or precision sensing, the mechanical oscillators are advantageous because they have high mechanical cue and also the speed of sound is vastly smaller than the speed of light and this tell us, for instance, in the context of FBAR filters to make very compact filters that fit into your cell phone. One of the challenges of achieving quantum control in mechanical oscillators has been that's similar to an atom or an ion that's trapped in Harmonic potential in a laser field.

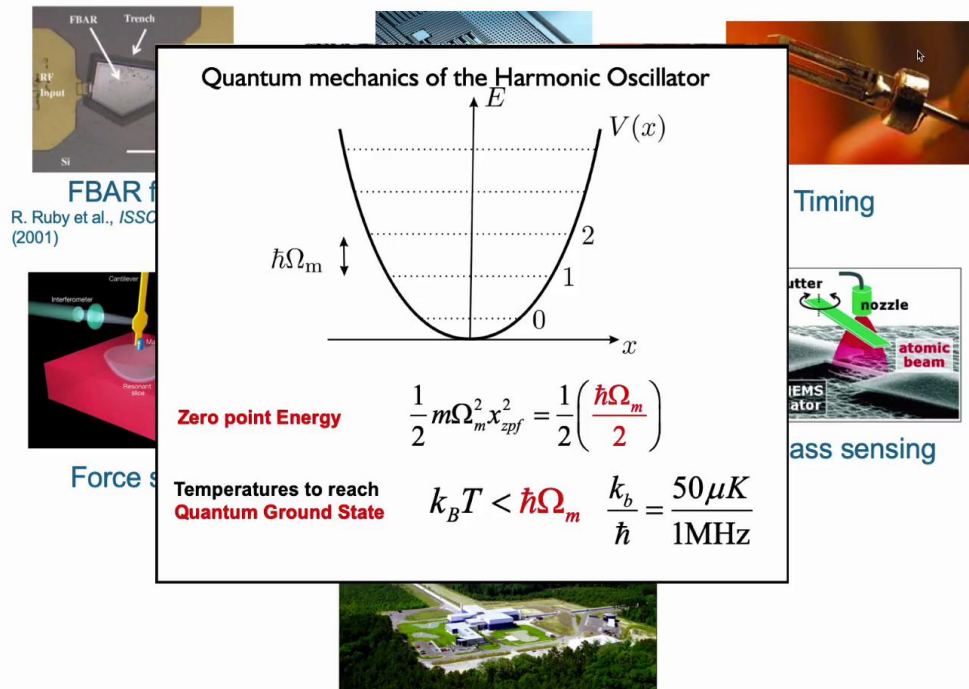
Notes

Summary



2m 44s

MECHANICAL OSCILLATORS IN SCIENCE AND TECHNOLOGY



Also mechanical oscillators obey, of course, laws of quantum mechanics. They have a well-defined zero-point energy. They have a zero-point fluctuation and also they have a quantum ground state and this quantum ground state for a macroscopic mechanical oscillator that oscillates here with the megahertz requires very low temperatures, 50 microkelvin for one megahertz oscillator. These are challenging to create and manipulate in a laboratory. They're far below what can be obtained with conventional [inaudible]. What cavity optomechanics has done, it has laid the foundation, okay, for manipulating and preparing mechanical oscillators in the ground state and making measurements at the level of the zero-point motion.

Notes

Summary



3m 51s

CAVITY OPTOMECHANICS

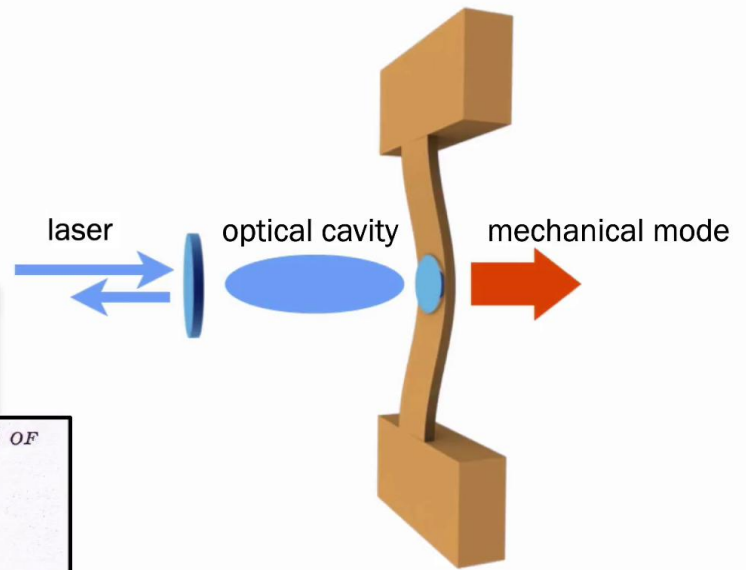


V. B. Braginsky

Г. 58 1970 Вып. 5
ИССЛЕДОВАНИЕ ДИССИПАТИВНЫХ ПОПДЕРОМОТОРНЫХ
ЭФФЕКТОВ ЭЛЕКТРОМАГНИТНОГО ИЗЛУЧЕНИЯ
В. Б. Бразинский, А. Б. Манукин, М. Ю. Тихонов
Описан эксперимент, в котором наблюдалось изменение декремента механиче-

INVESTIGATION OF DISSIPATIVE PONDEROMOTIVE EFFECTS OF
ELECTROMAGNETIC RADIATION

V. B. BRAGINSKIĬ, A. B. MANUKIN, and M. Yu. TIKHONOV
Moscow State University
Submitted October 17, 1969



In this mooc of cavity quantum optomechanics, we'll introduce the field of optomechanics. This field traces back to pioneering work of Vladimir Braginsky in the 70s who was really the first person to think about the modifications that mechanical oscillator experience when they're exposed to resonant laser light. An optomechanical system at its core is an extremely simple, okay, optical system. It's similar to a Michelson interferometer composed of two mirrors where one of the mirrors can be thought about to be mechanically compliant. The mechanical oscillator's position is coupled with the optical field by the laser radiation pressure force, by the radiation pressure force exerted by light. And likewise the motion of the mirror itself also changed the property of the optical interferometer and this mutual interplay has been studied in the pioneering work of Braginsky who were in his 60s and 70s actually, pointed out even before the invention of the laser that electromagnetic radiation confined to optical resonators allows to create dissipative effects in terms of amplification and cooling of mechanical motion. And this laid the early phase of the groundwork what is now known as cavity optomechanics.

Notes

Summary



4m 28s

WHAT YOU WILL LEARN?

the concepts and tools required for conducting research in the field of cavity optomechanics.

The theoretical basis for studying both mechanical and optical resonators

The new physics emerging from their interaction.

The various tools used in designing a cavity optomechanical experiment.

What will you learn in this course? What you'll learn in this course is first of all the theoretical basis for studying both mechanical and optical resonators, mechanical resonators ubiquitous in NEMS and MEMS and optical resonators being used in a wide variety of experiments ranging from laser gravitational wave detectors to any optical laser to other sensitive devices to measure forces. You also learn new physics that arises from their interaction, the interaction being most notably the radiation pressure.

Notes

Summary



5m 37s

COURSE CONTENT

Week 1
Introduction

Week 2
Optical and mechanical
resonators

Week 3
Classical dynamics

Week 4
Quantum dynamics

Week 5
Quantum correlations

Week 6
Experimental methods

You'll learn about the various tools in designing a cavity optomechanical experiment and this is composed into a six week mooc. In week one, there will be introduction. In week two, optical mechanical resonators. Week three will discuss classical dynamics resulting from radiation pressure and in week four, the quantum dynamics. And week five will devote an attention to quantum correlations that arise from the radiation pressure interaction and in week six, discuss the rich experimental methods that are used in this field.

Notes

Summary



6m 07s

TAUGHT BY EXPERTS OF THE FIELD



Tobias Kippenberg



Albert Schliesser



Florian Marquardt



Pertti Hakonen



David Vitali



Samuel Deleglise



Markus Aspelmeyer



Roman Schnabel



Rémy Braive



Eva Weig



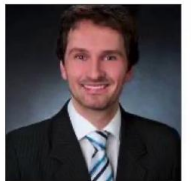
Dries Van Thourhout



Gary Steele



Paul Seidler



Peter Degenfeld-Schonburg



Overall this course will be given by experts in their fields, experts that have worked in optomechanics for as long as 20 years and have helped to shape and define the field. And this includes Albert Schliesser in the University of Copenhagen, Florian Marquardt in Erlangen, Pertti Hakonen in Aalto, David Vitali at Università Di Camerino, Samuel Deleglise at Sorbonne Université, Markus Aspelmeyer in Vienna University, Roman Schnabel, University of Hamburg now, Rémy Braive at the CNRS, Eva Weig at the Tech University of Munich, Dries Van Thourhout at Ghent University, Gary Steele in Delft, Paul Seidler, IBM and Peter Degenfeld-Schonburg from BOSCH. We hope that the mooc that we've put together will help you to appreciate both the fundamentals and also the prospects and enticing applications that quantum optomechanics allows to uncover.

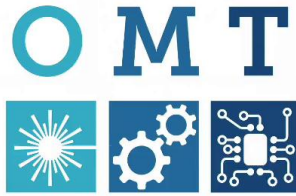
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6m 37s

THIS COURSE IS FUNDED BY



OPTOMECHANICAL
TECHNOLOGIES

Marie Skłodowska-Curie
European Training Network



A consortium of 12 academic and 2 industrial partners

The OMT network was funded as part of a Marie Curie European Training Network. It included twelve academic and industrial partners and this mooc is a result of the support that we've obtained.

Notes

Summary



7m 26s