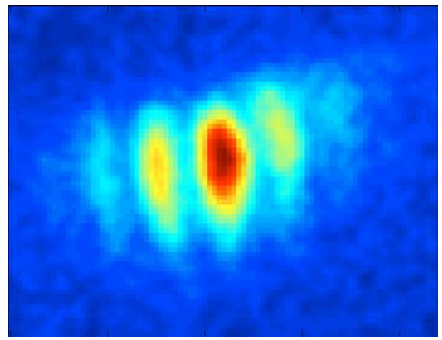
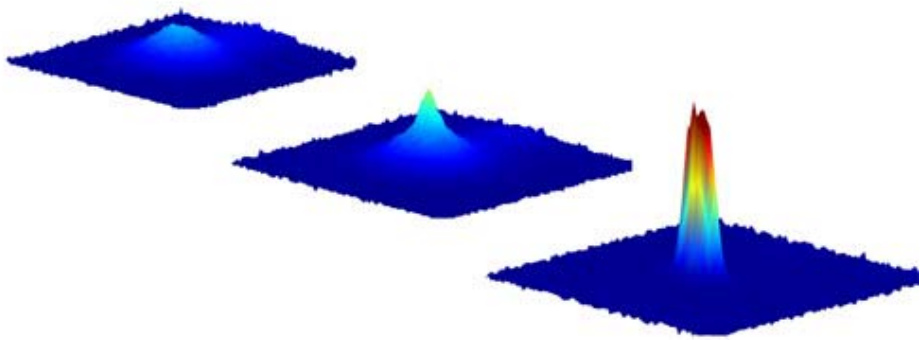
Physics 404 and Physics 690-03

Introduction to Atomic Physics and Quantum Optics





[images courtesy of Thywissen group, U of T]

Instructors

Prof. Seth Aubin

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web: http://www.physics.wm.edu/~saubin/index.html

Jim Field

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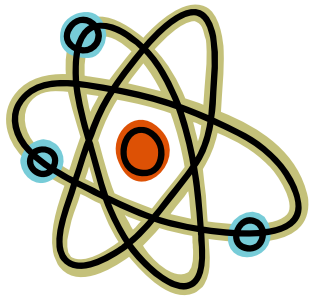
Office hours:

Monday:	4:30-5:30 pm (Field)
Thursday:	5-6 pm (Aubin)

Course Objectives (I)

Introduce the ***basic physics***, **theory**, **current research topics**, and **applications** of ***Atomic Physics and Quantum Optics***.



Topics:

- Classical and quantum **coherence**.
- **2-level atoms**, atom-light interactions, Bloch sphere.
- Spontaneous emission, **decoherence**.
- **Schrödinger** equation, **density matrix** , **quantum Monte Carlo**.
- **Angular momentum** of light and atoms.
- **Multi-level** quantum systems, diatomic molecules.
- **Laser cooling and trapping**.
- Quantum theory of light, **dressed atoms**, squeezing.
- **Entanglement**, Quantum information, Bell inequalities, EPR paradox.
- **Quantum gases:** Bose-Einstein condensation, degenerate Fermi gases.

Course Objectives (II)

Experimental Demonstrations

Seeing is believing … Demonstration topics:

- **Research lab visits.**
- **laser cooling and trapping**.
- **Doppler broadening.**
- **Saturation spectroscopy.**
- **Spatial and temporal coherence.**
- **Particle behavior of light.**

etc ...

Scientific Articles and Presentations

Practice reading and writing scientific articles and making science presentation.

Course Work

- **Problem sets:** weekly, extra problems for graduate students.
- **Participation:** class attendance, classroom discussion.
- **Midterm** (before spring break).
- **Undergraduate students** (work done in teams of two):
  - **Final paper** (4 pages, single space, *Phys. Rev. Lett.* format).
  - **Oral presentation** on the same subject matter.
- **Graduate students:** **Final exam** (May 10, 2-5pm)

Undergraduate Grading

Problem sets	40 %
Participation	10 %
Midterm	15 %
Final paper	20 %
Oral presentation	15 %
Total	**100 %**

Graduate Grading

Problem sets	50 %
Participation	10 %
Midterm	15 %
Final Exam	25 %
Total	**100 %**

References

Text: About half of the course materials and almost all of the problem sets will be taken from the following required text for the course:

Elements of Quantum Optics by P. Meystre and M. Sargent III [Springer, 4th ed., 2007]

The rest of the course materials will be taken from original physics papers and the following texts:

Quantum Mechanics (non-relativistic theory), Landau and Lifshitz.

Laser Cooling and Trapping, Metcalf and van der Straten

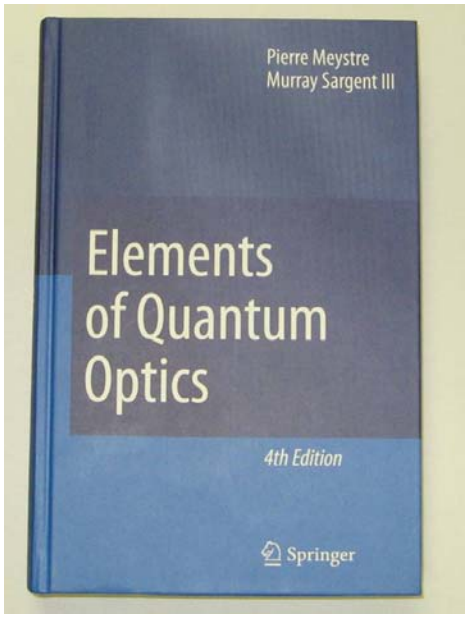
Quantum Theory of Light, Loudon

Optical Coherence and Quantum Optics, Mandel and Wolf

Atomic Physics, Foot

Bose-Einstein Condensation in Dilute Gases, Pethick and Smith

Quantum Mechanics, by Cohen-Tannoudji, Diu, Laloë



Schedule (I)

Week 0: 1/20-22 **Intro to Atomic Physics**
Introduction to atom-light interactions, semi-classical atomic physics.

Week 1: 1/25-29 **Coherence**
Interference, first and second order coherence, correlation functions.

Week 2: 2/1-5 **Quantum atomic physics: 2-level atoms**
2-level systems, Rabi Flopping, Bloch sphere.

Week 3: 2/8-12 **AC Stark Shift**
Dressed atom picture, optical dipole trapping, optical tweezers.

Week 4: 2/15-19 **Density Matrix**
Decoherence, spontaneous emission, optical Bloch equations.

Week 5: 2/22-26 **Monte Carlo numerical methods**
Classical Monte Carlo, Quantum Monte Carlo.

Week 6: 3/1-5 **Multi-level atoms**
Selection rules, fine and hyperfine structure, 3-level systems.

---------- Spring Break ----------

Schedule (II)

Week 7: 3/15-19 **Laser Cooling and Trapping**
Doppler cooling, Sysiphus cooling, magnetic trapping.

Week 8: 3/22-26 **Photons: Quantization of the Electromagnetic Field**
Simple introduction to quantum field theory.

Week 9: 3/29-4/2 **Quantum Theory of Atom-Photon Interactions**
Stimulated emission and absorption, spontaneous emission, squeezing.

Week 10: 4/5-9 **Quantum Entanglement**
EPR paradox, Quantum computing and Shor's Algorithm, Bell's Inequalities.

Week 11: 4/12-16 **Atomic Quantum Optics**
Atom-atom interactions, Bose-Einstein Condensation, degenerate Fermi gases.

Week 12: 4/19-23 **Oral Presentations**
Final papers due on 4/26. Undergraduate oral presentations.

Week 13: 4/26-30 **Special Topics (or catch-up week)**
Quantum simulations, nuclear physics and parity violation, diatomic molecules.

May 10, 2010, 2-5pm **Final Exam (graduate students only)**

Quantum Mechanics, Atoms, and Photons

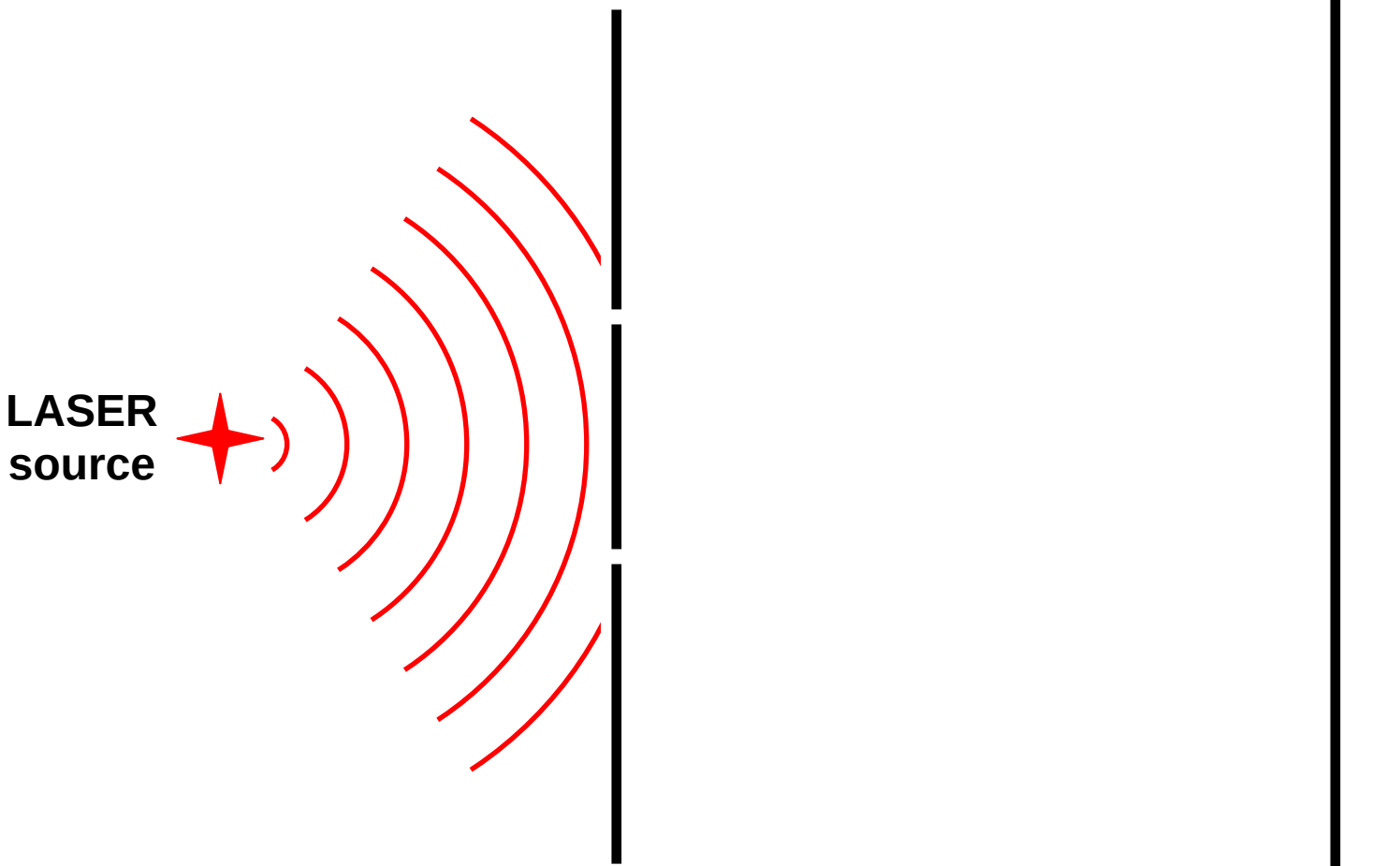
Review and Questions

1. What do you know about light and photons?

2. What do you know about atoms?

3. How was Quantum Mechanics discovered?

Light as a wave



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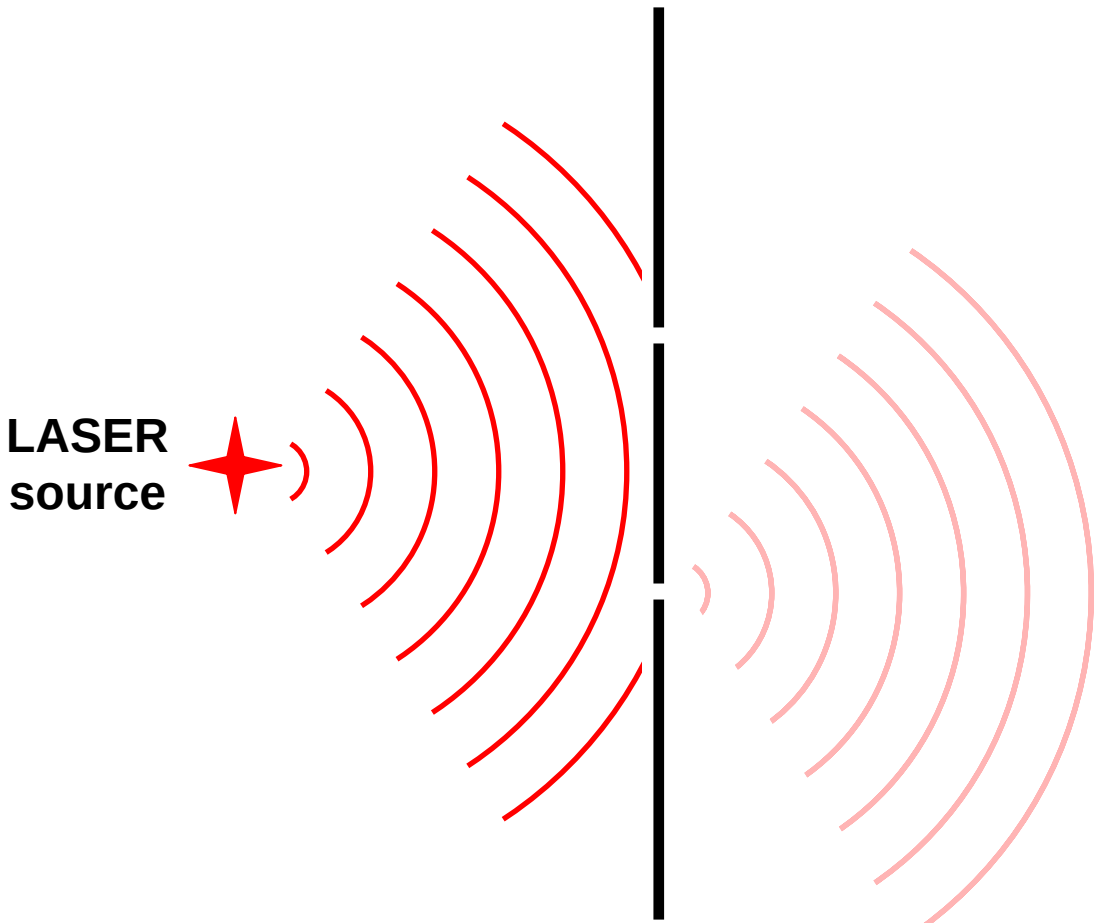
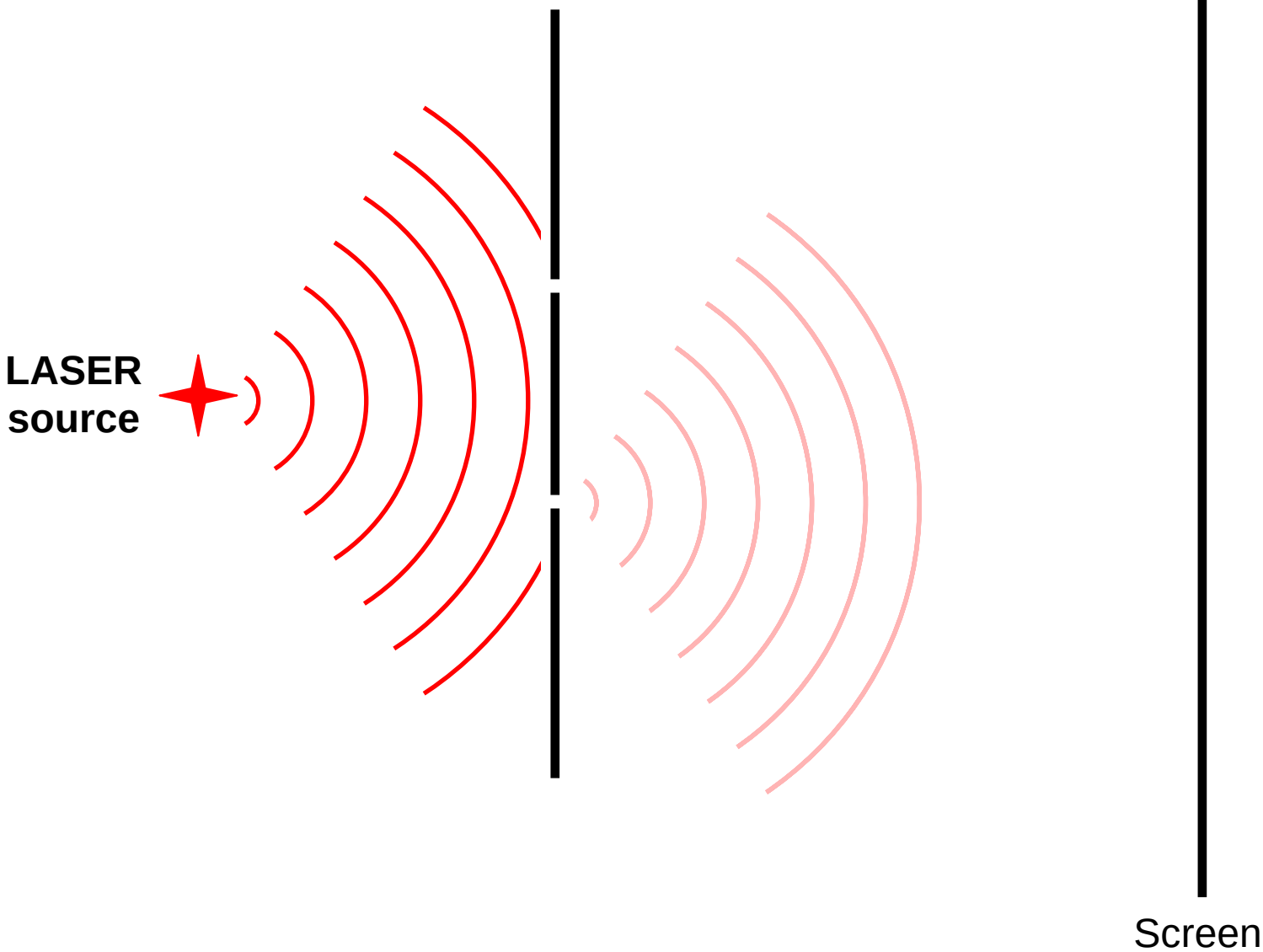


Light waves **diffract** as they go through the slits

Screen

Light as a wave



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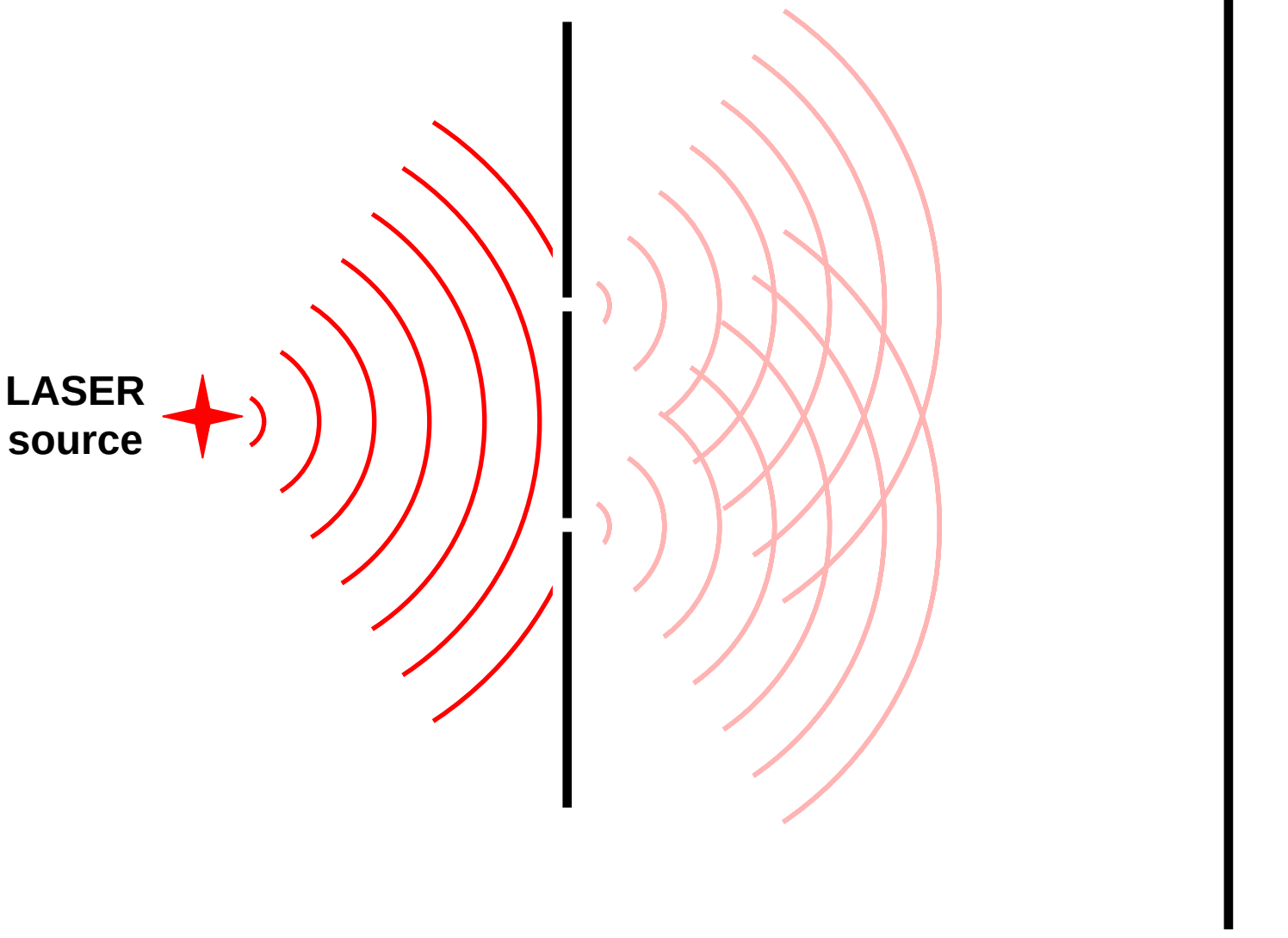

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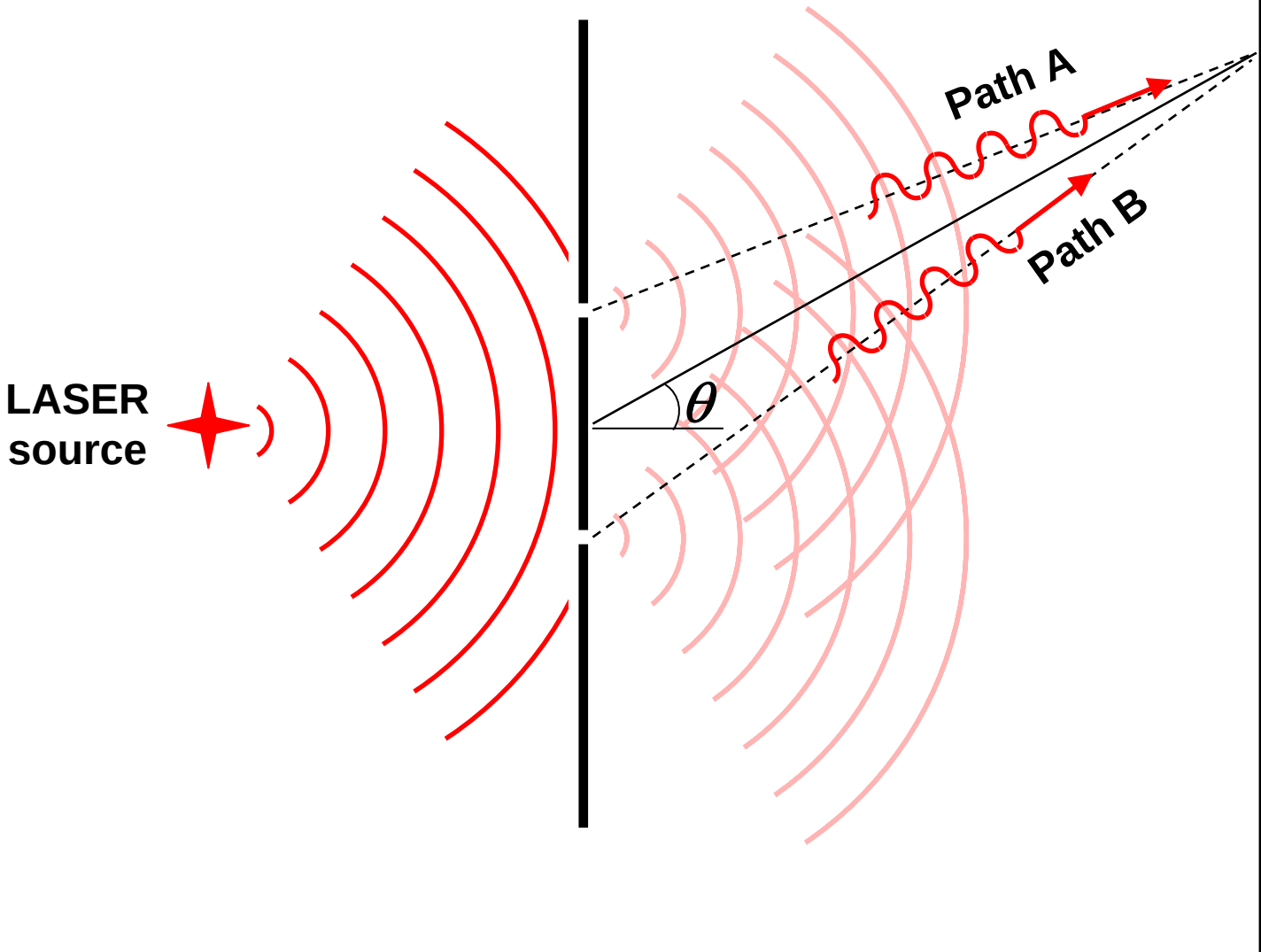

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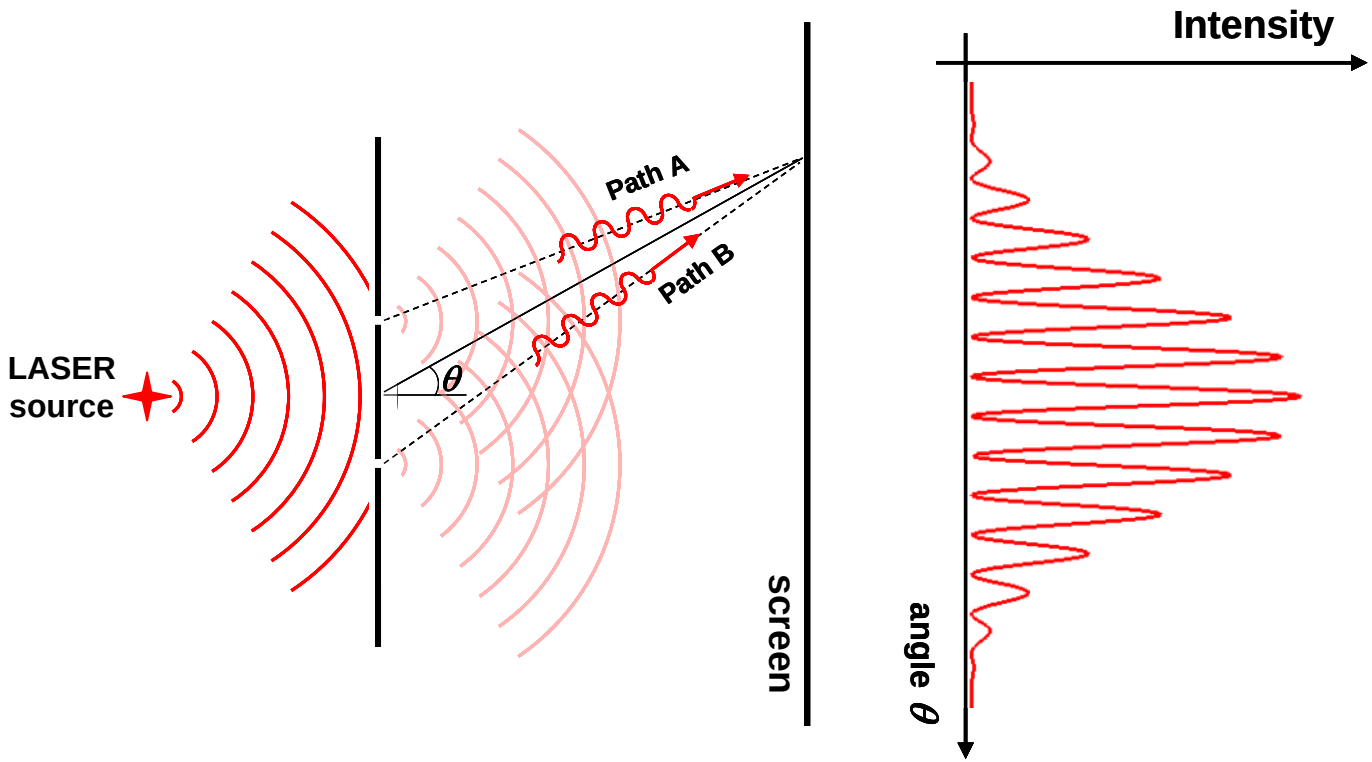
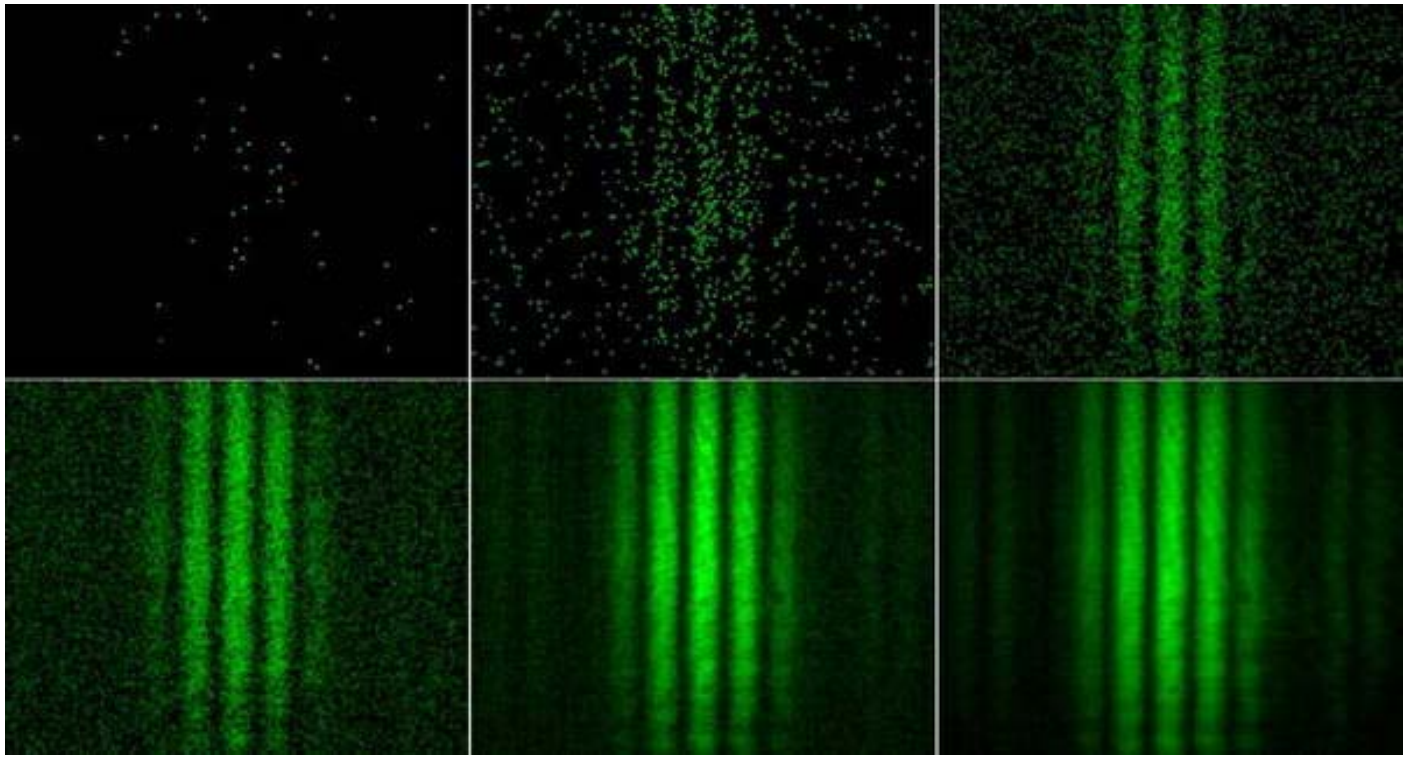


Light waves **interfere**.

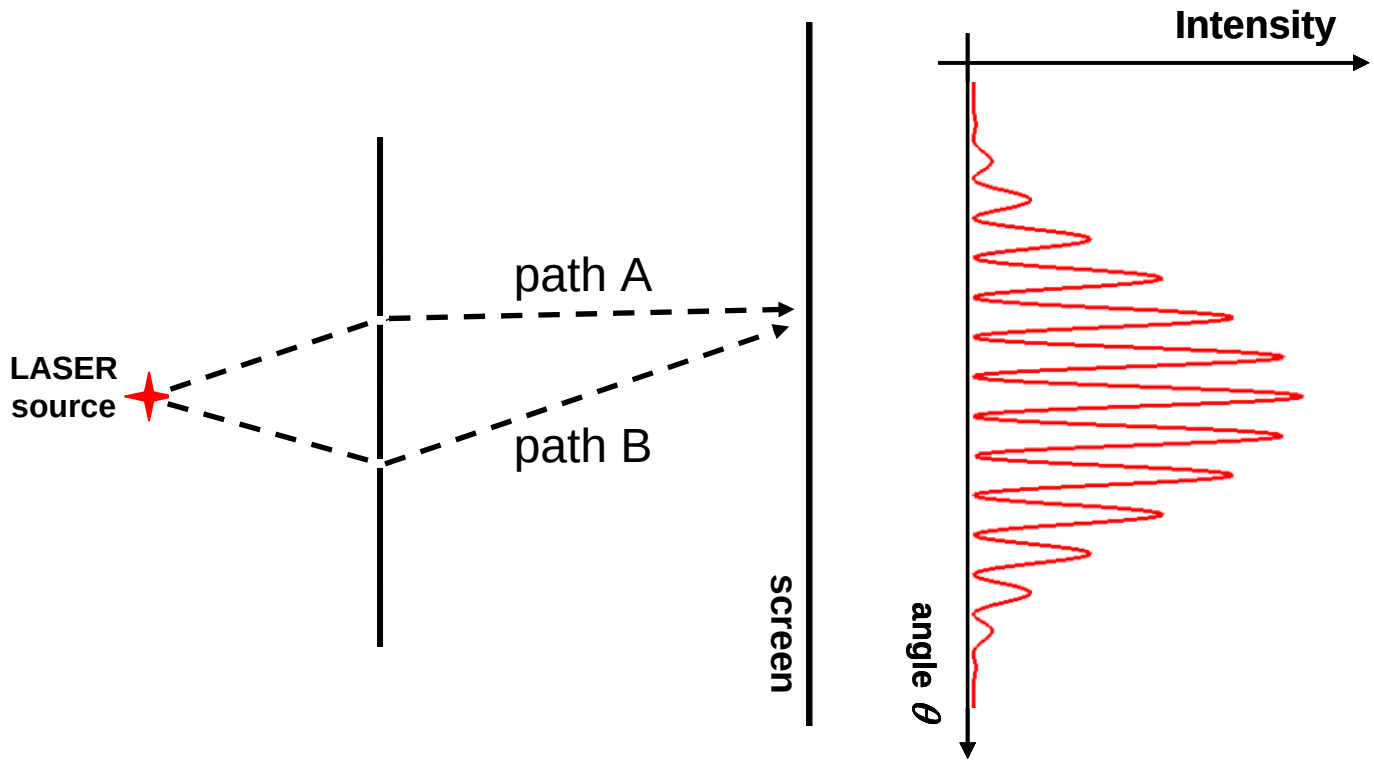
Also works for single photons !!!



[A. L. Weiss and T. L. Dimitrova, Swiss Physics Society, 2009.]

Experiment uses a CCD camera (i.e. sensor in your digital camera).

Photons follow 2 paths simultaneously



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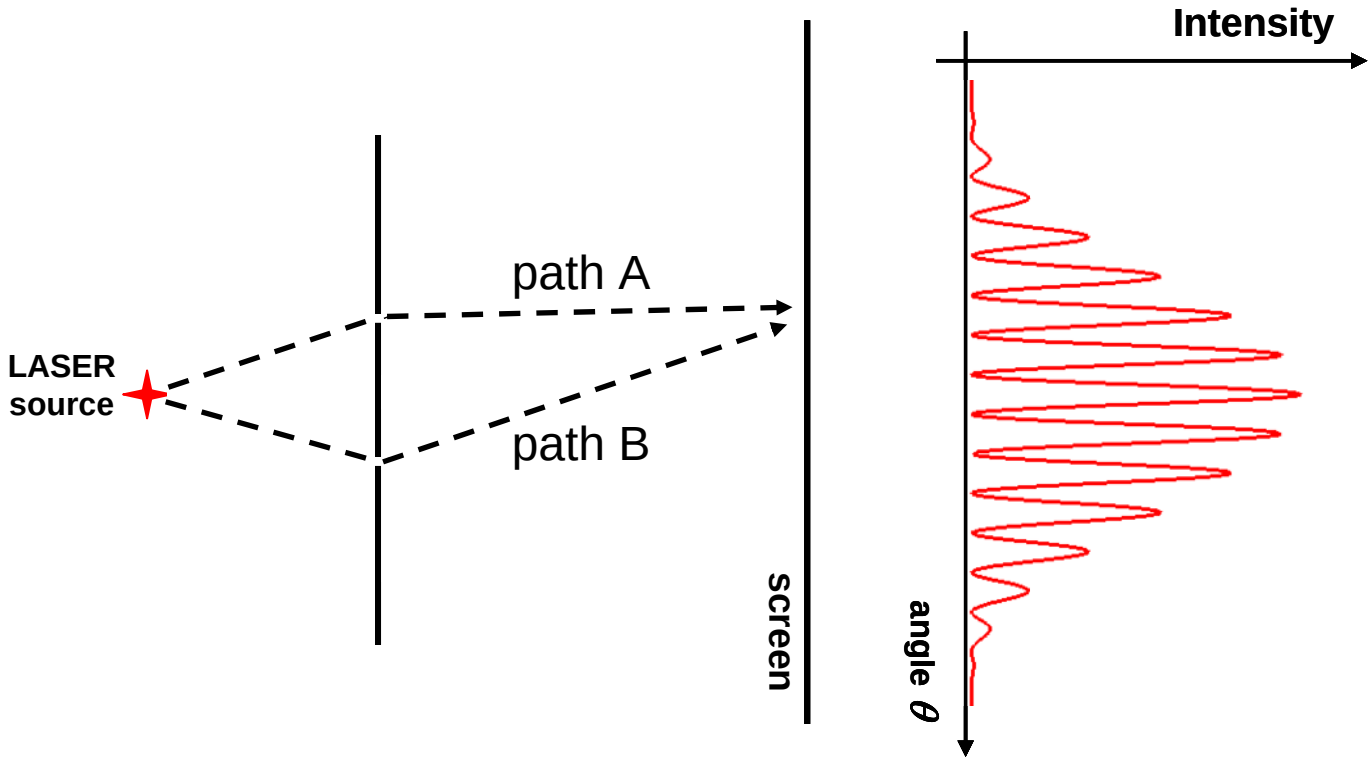
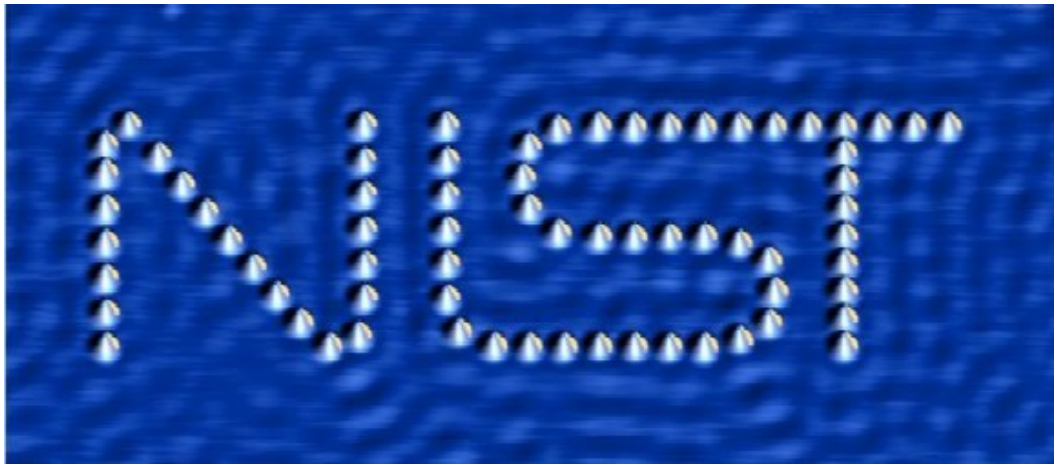
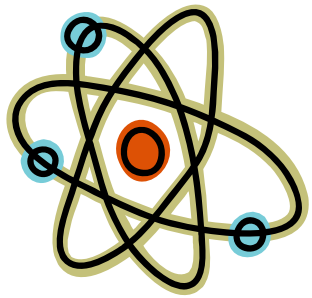


$$|\psi\rangle_{photon} = |A\rangle + e^{i\phi}|B\rangle$$

LIGHT IS A

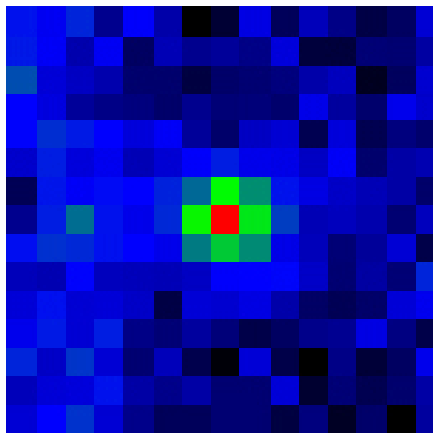
Atoms





Cobalt atoms on a copper surface (scanning tunneling microscope image)

[image from www.nist.gov]

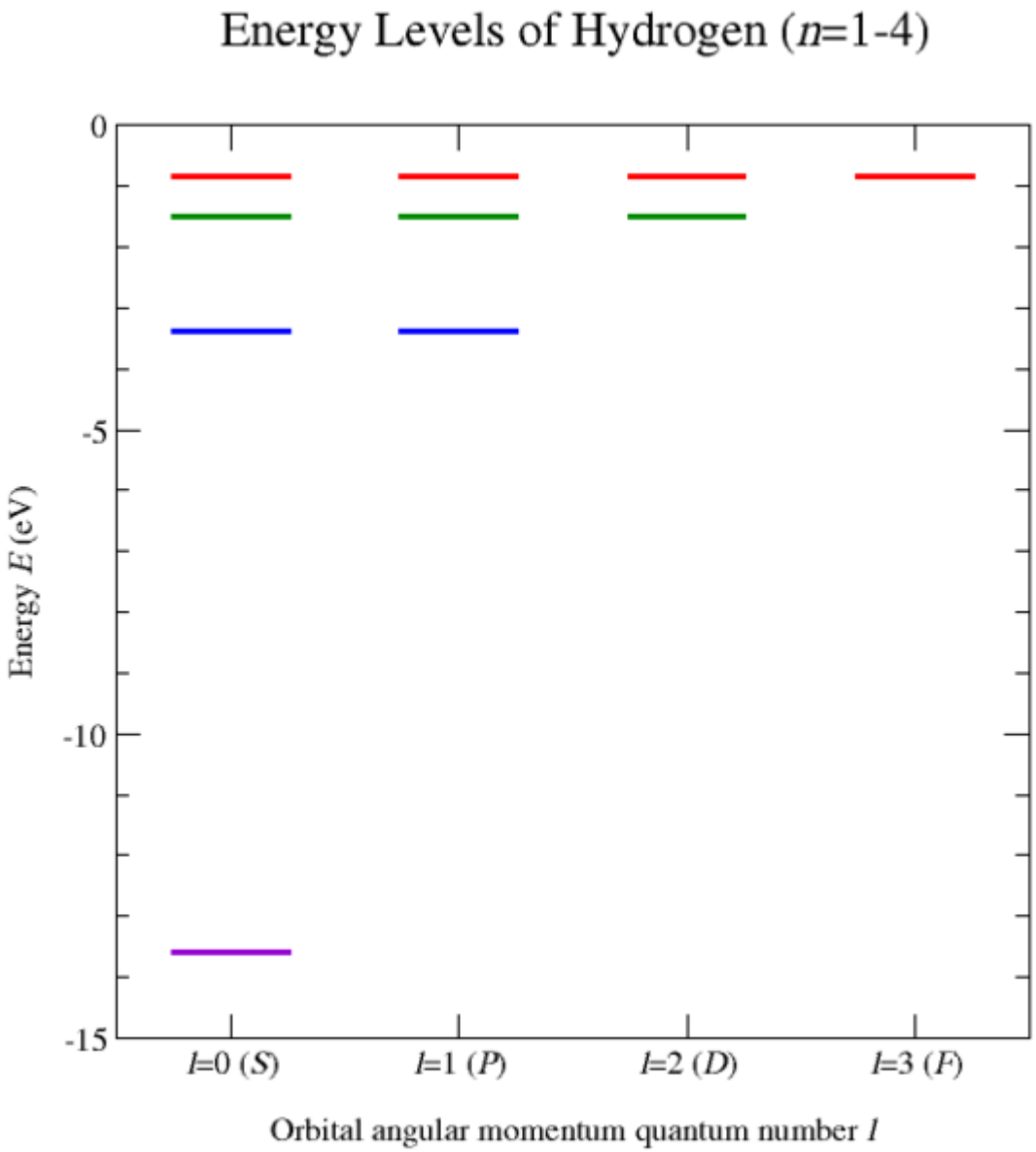


Single Rb atom
(laser cooled and trapped)

[image from Grangier group, www.optique-quantique.u-psud.fr]

Matter is also a

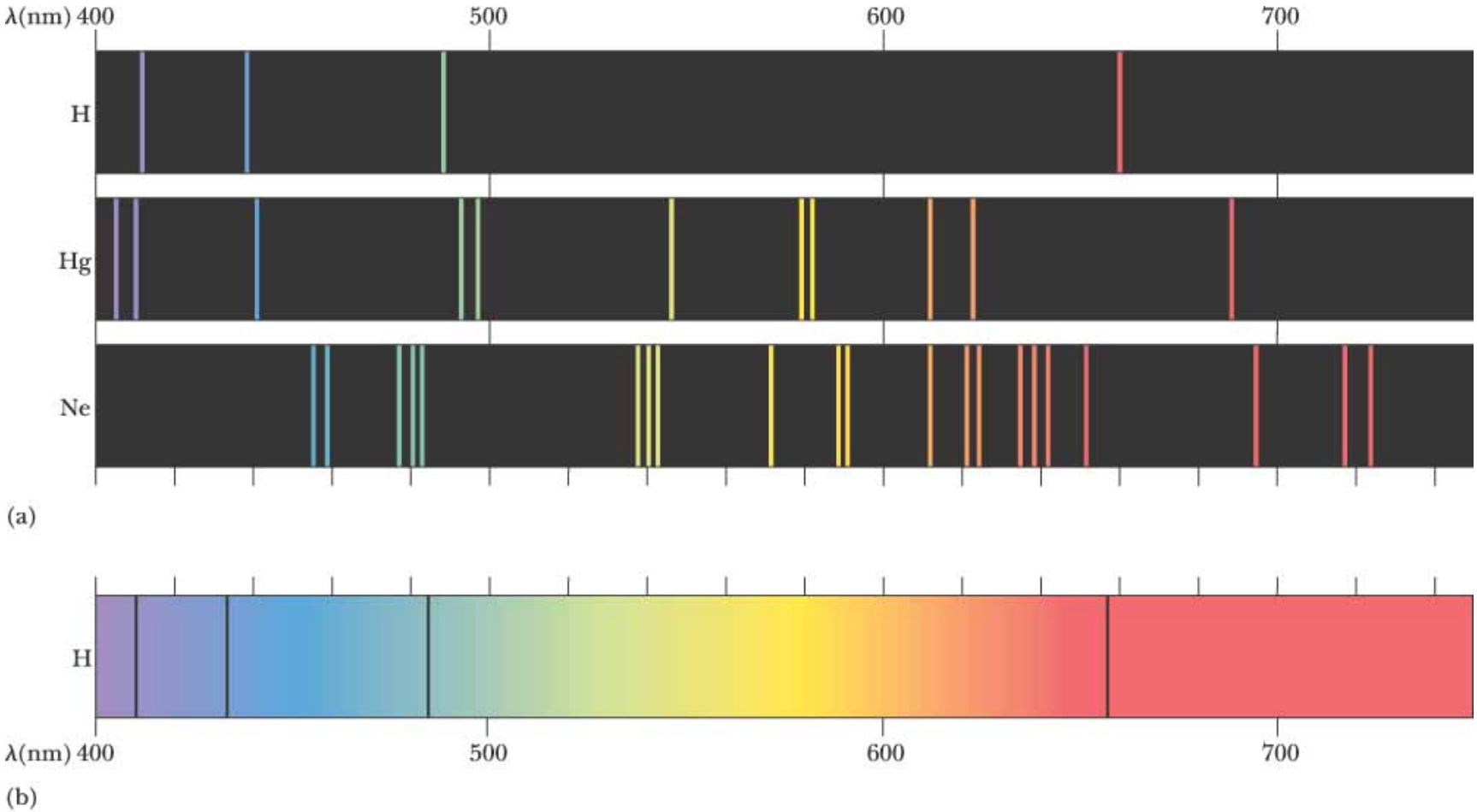
Quantum Version of Atoms



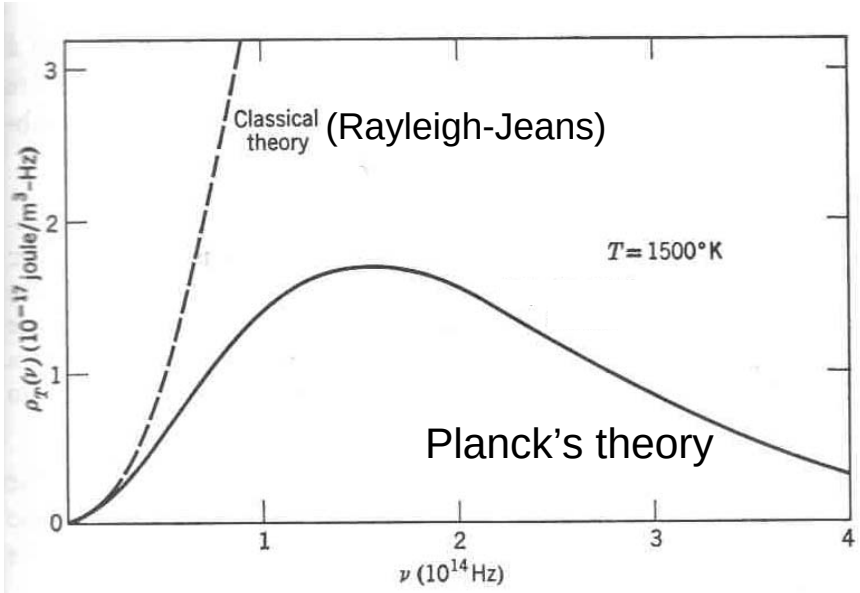
[Figure from wikimedia.org]

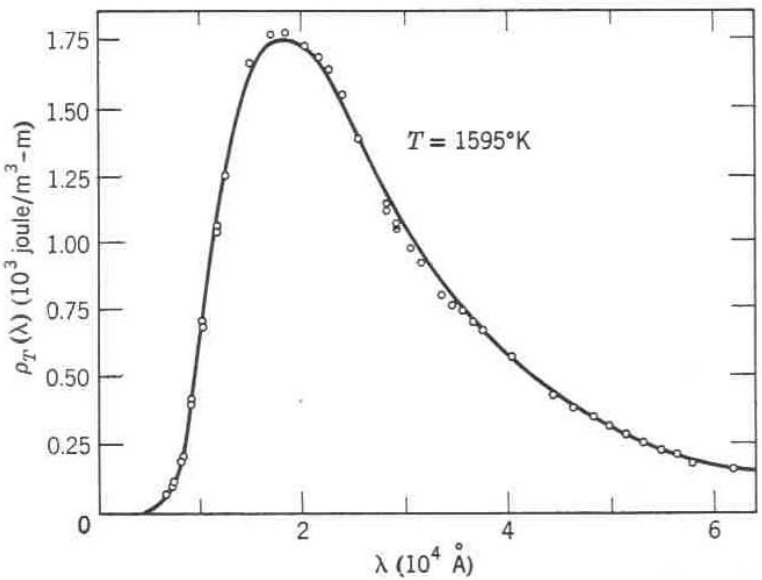
How was quantum mechanics discovered?

Atomic Emission and Absorption Spectra



Blackbody Radiation: Rayleigh-Jeans vs. Planck





Experiment vs. Theory
(Coblentz data, 1916)

[figures adapted from ***Quantum Physics*** by Eisberg and Resnick, 1985.]

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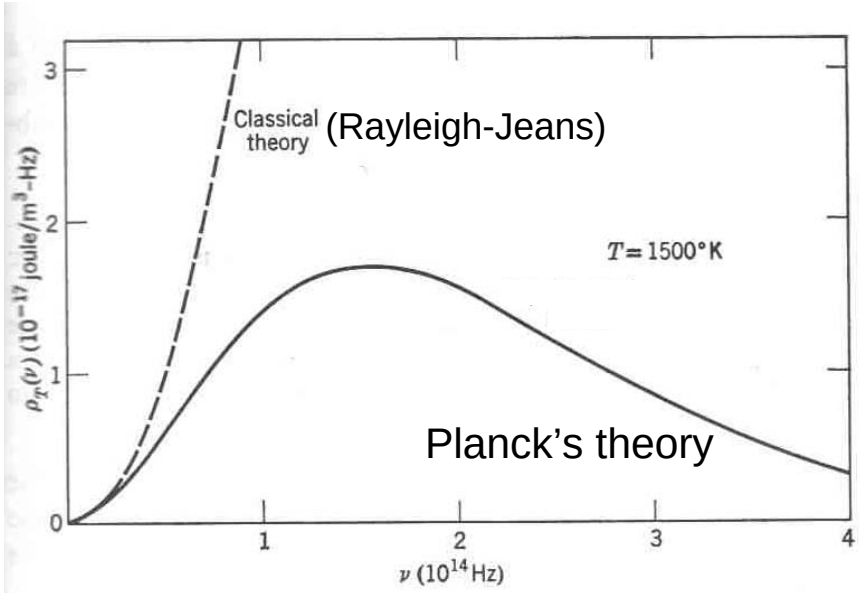
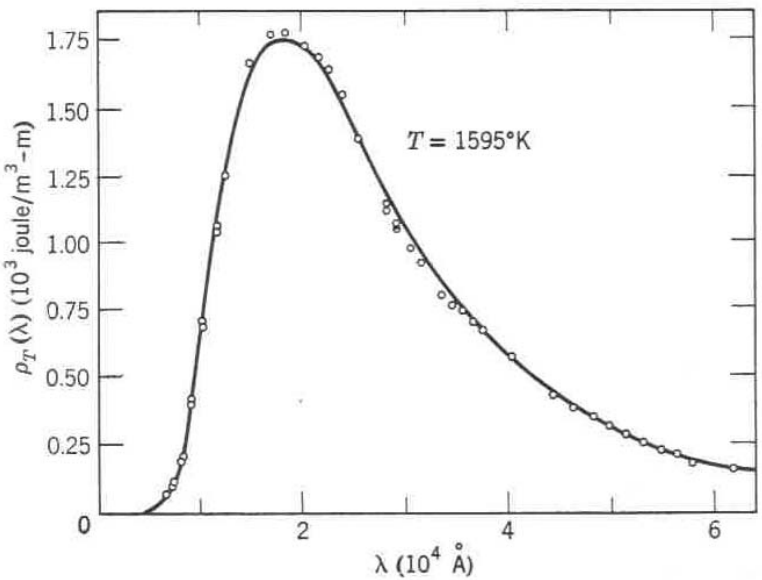


$$E = \hbar\omega$$



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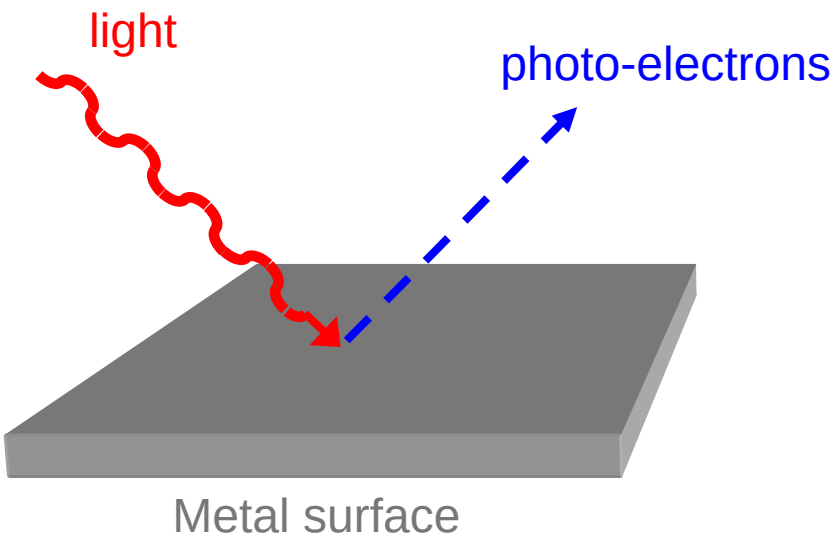

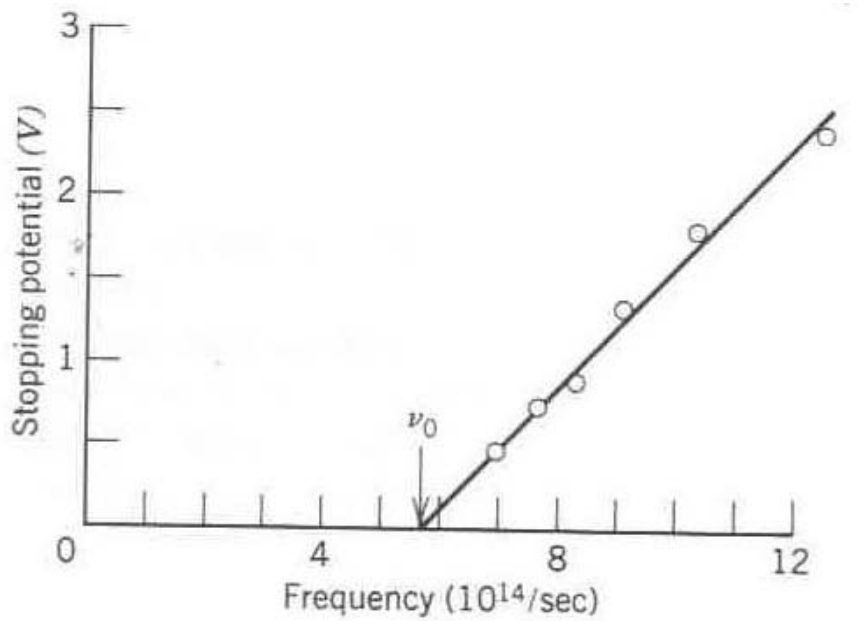

Millikan's photo-electric data for sodium

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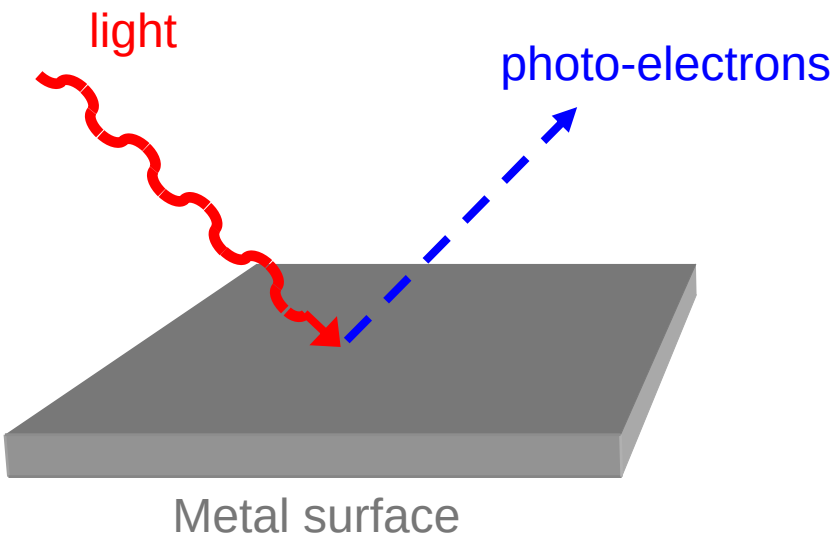

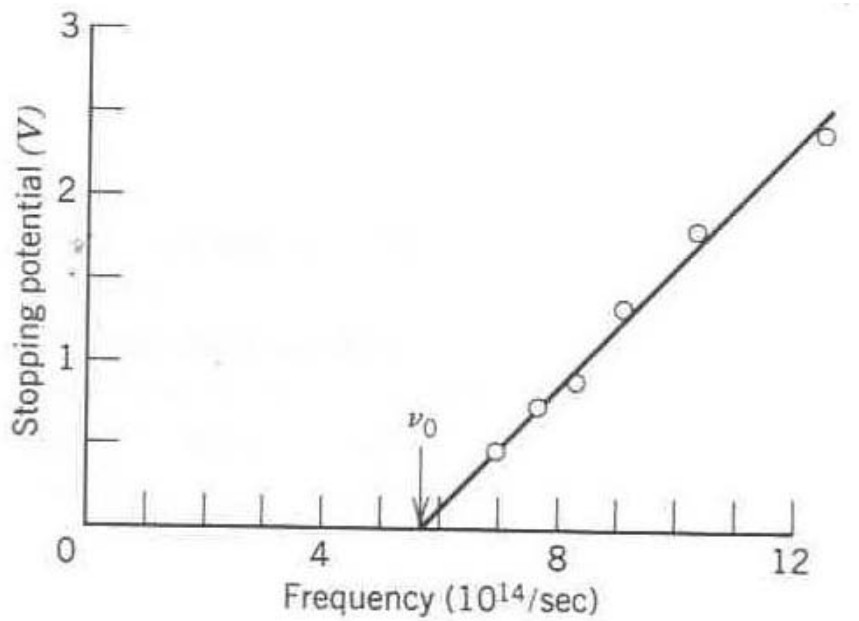

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- How do you treat the **phase** of a photon(s)?
- Do photons obey the **Heisenberg uncertainty relations**?

What's special about AMO Physics?

AMO Physics = Atomic, Molecular, and Optical Physics.

- Test bed for Quantum Mechanics.
- Energy resolution of internal levels at the **1 part per 10^9 – 10^{14}.**
- 100+ years of spectroscopy.
- **Frequency** measurements at **10^3-10^{15} Hz**.
- *Ab initio* calculable internal structure.
- Precision tests of QED to 9-digits (measurement to 12-digits)

Electron's g-factor: g_e = 2.002 319 304

Applications

- Inertial navigation, force sensing.
- Astronomy, nuclear, particle, and condensed matter physics.
- GPS, telecommunications, data storage.