Now that you have (I hope) a sound understanding of what quantum mechanics *says*, I should like to return to the question of what it *means*…

-David Griffiths (Afterword of Intro to QM)

- What is a quantum state, really?

$$\psi = \phi(r)\,|\chi\rangle$$

Tells us the statistical probability of a certain outcome in a measurement.

- Three "typical" interpretations of this:
  - **Realist:** The physical system had the measured attribute BEFORE you measured
  - **Orthodox:** The act of measurement created the measured attribute (in accordance with ψ)
  - **Agnostic:** Ignore this question on the grounds that it is unknowable

Either way, we got problems:

- The **Realist** says QM is an incomplete theory because even if you know everything QM says (ψ), you still don't know everything about the system. There must be some better theory.

- The **Orthodox view** says since the act of measurement creates the attribute and since repeated measurement must give the same answer the wavefunction must collapse (very un-Schrodinger-like, no?)

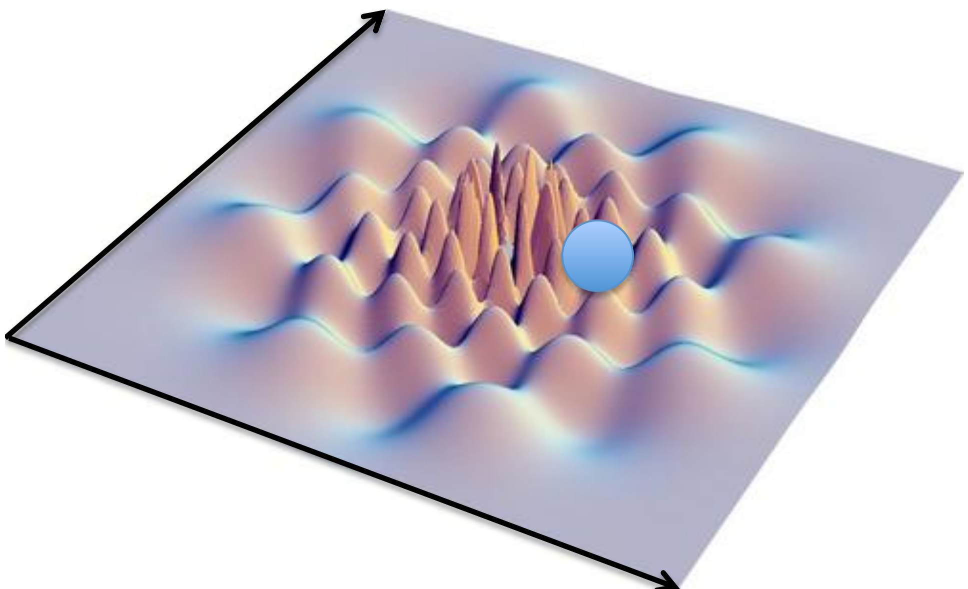
- The **agnostic** gave up a long time ago.

The Realist and the idea of hidden variables

- Suppose: ψ is not the whole story and quantum states are characterized by a, **as yet unknown quantity, λ**.
- We don't know how to measure or calculate λ, so we call it a **hidden variable**.

Orthodox view

ψ

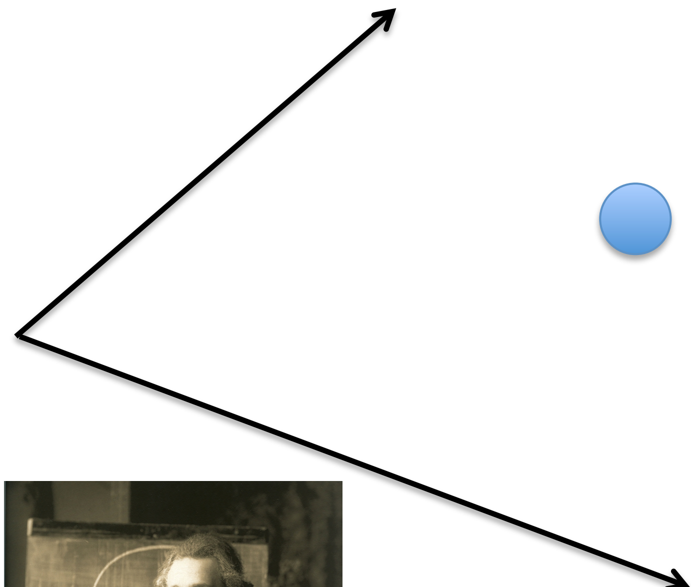


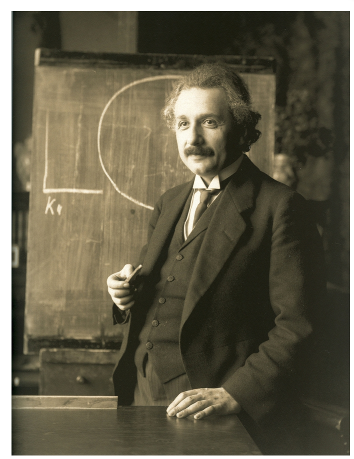
Bohr

Heisenberg

Realist view

$\psi + \lambda$





Einstein

In this class, we’ll see who’s right by doing a type of experiment originally proposed by J.S. Bell in 1964

and

convincingly carried out by Aspect, Grangier, and Roger in 1982

The original literature (very accessible)

- A. Einstein, B. Podolsky, and N. Rosen, Physical Review **47**, 777 (1935).
- J.S. Bell, Physics **1**, 195 (1964).
- A. Aspect, P. Grangier, and G. Roger, Physical Review Letters **49**, 91 (1982).

Phys 180Q
Quantum Optics Lab
Week 1

1. ~~Motivation~~
2. Syllabus & Class Organization
3. Introduction to components
4. Laser safety
5. Basic Skills lab (Week 1)

Syllabus & Class Organization

- Syllabus
- Each week:
  - Prelab (for the week) due on Wednesday
  - Lab (from the preceding week) due at the start of your lab session
  - Grading will be based on Prelab, Lab, & Final Write-up
  - Lab Schedule for Week n: [NEXT SLIDE]

Syllabus & Class Organization`

…

Wednesday	Thursday	Friday
nth Lecture (n-1)th Prelab due	(n-1)th Lab Report due Brendan Wenxin Jiayu	(n-1)th Lab Report due Elias Matt Gengming Josh

Monday	Tuesday	Wednesday	Thursday	Friday
(n-1)th Lab Report due	(n-1)th Lab Report due Vivian Janet Lauren Alex	(n+1)th Lecture nth Prelab due	nth Lab Report due [4 names here]	nth Lab Report due [4 names here]

The goals of this class

- Understand modern interpretation of QM and QM measurement (and its shortcomings)
- Learn modern optics techniques

Teaching philosophy:

1. You learn by doing.
2. You can't understand the results of QO without understanding the techniques. Thus, we will have six introductory labs which will teach you about optics, lasers, cavities, etc.

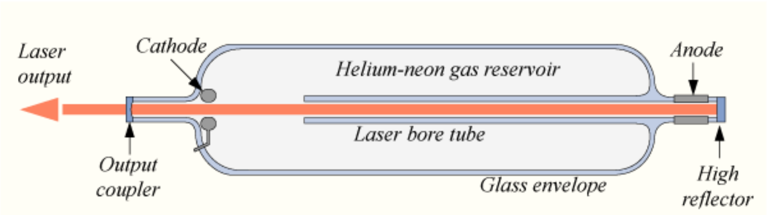
Spoiler Alert!

- We’re going to use **photons** as our quantum particle and we’re going to use their **polarization** as our quantum degree of freedom

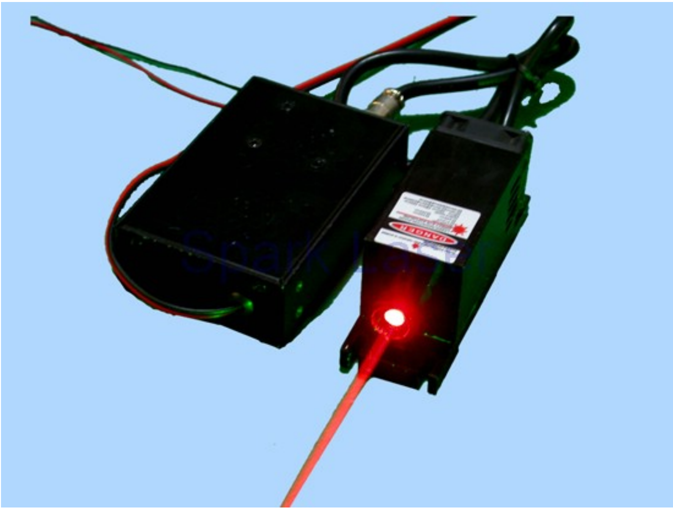
- So get ready to learn a lot about light!

Lasers

HeNe (gas) laser

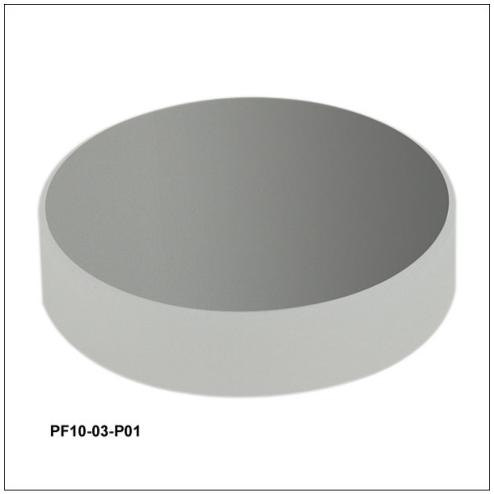


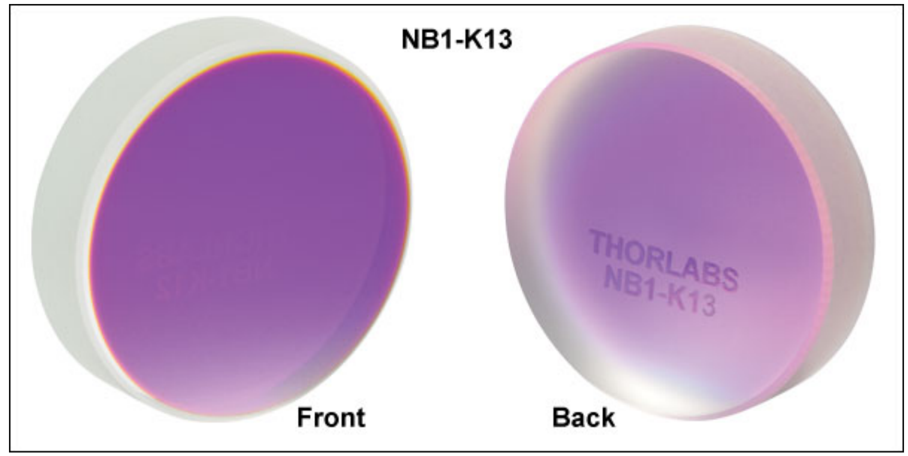
Diode laser (solid state)



Introduction to optical components

Mirrors





Metallic mirrors
Broadband
Cheap

Dielectric mirrors
(Bragg reflection)
Narrowband, $$$
Highest Reflectivity
Highest damage threshold

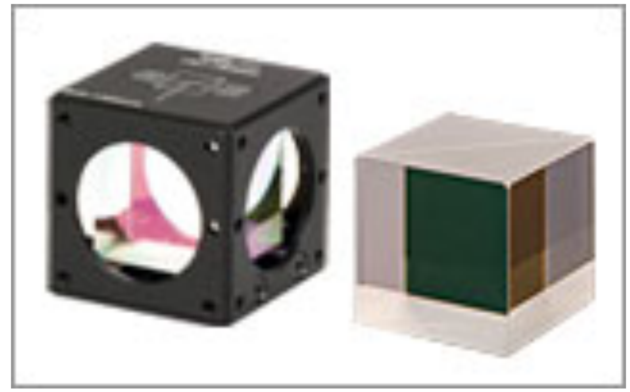
Introduction to optical components

Mirror Assembly

Thumb screws give precise angle control
Post give height adjustment
++ and - - to each; know your application

Polarizers

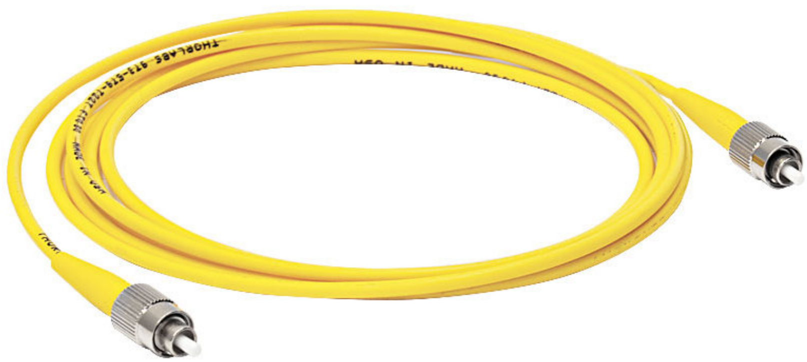
Film or wire polarizers



Polarizing beam splitter cubes

Glan-Thompson polarizers

Fibers



Single-mode optical fiber

Multi-mode optical fiber

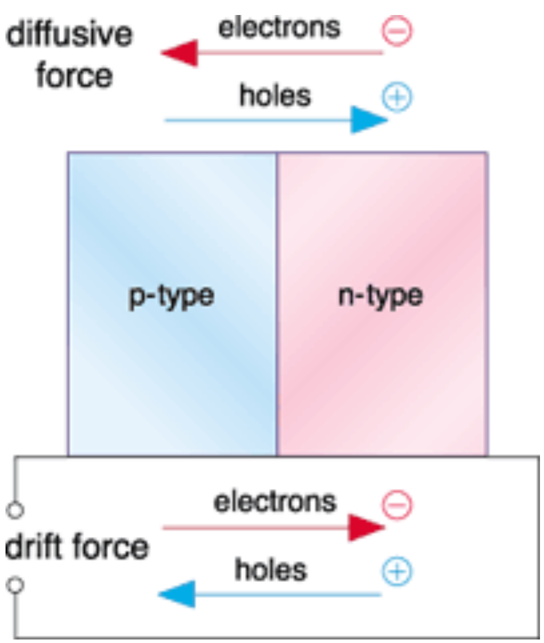
Photodetectors: Convert EM radiation into detectable electronic signal

Photomultiplier tubes (PMTs)

Detectable electron current

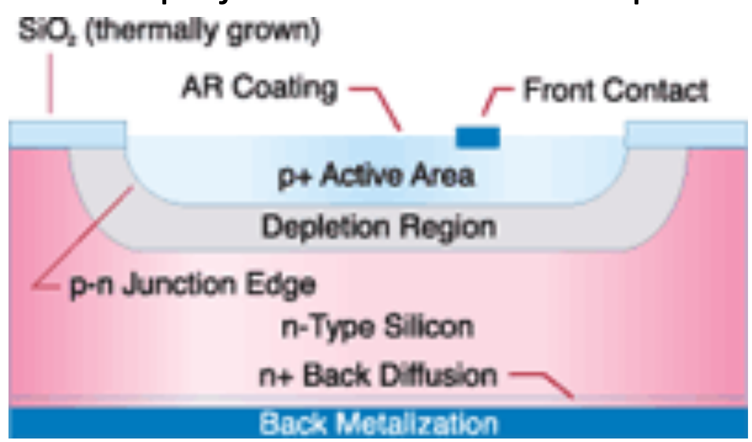
Photodetectors: Convert EM radiation into detectable electronic signal

Photodiodes (PDs)



n-type: excess electrons
p-type: excess holes

At the pn junction there is a depletion region:



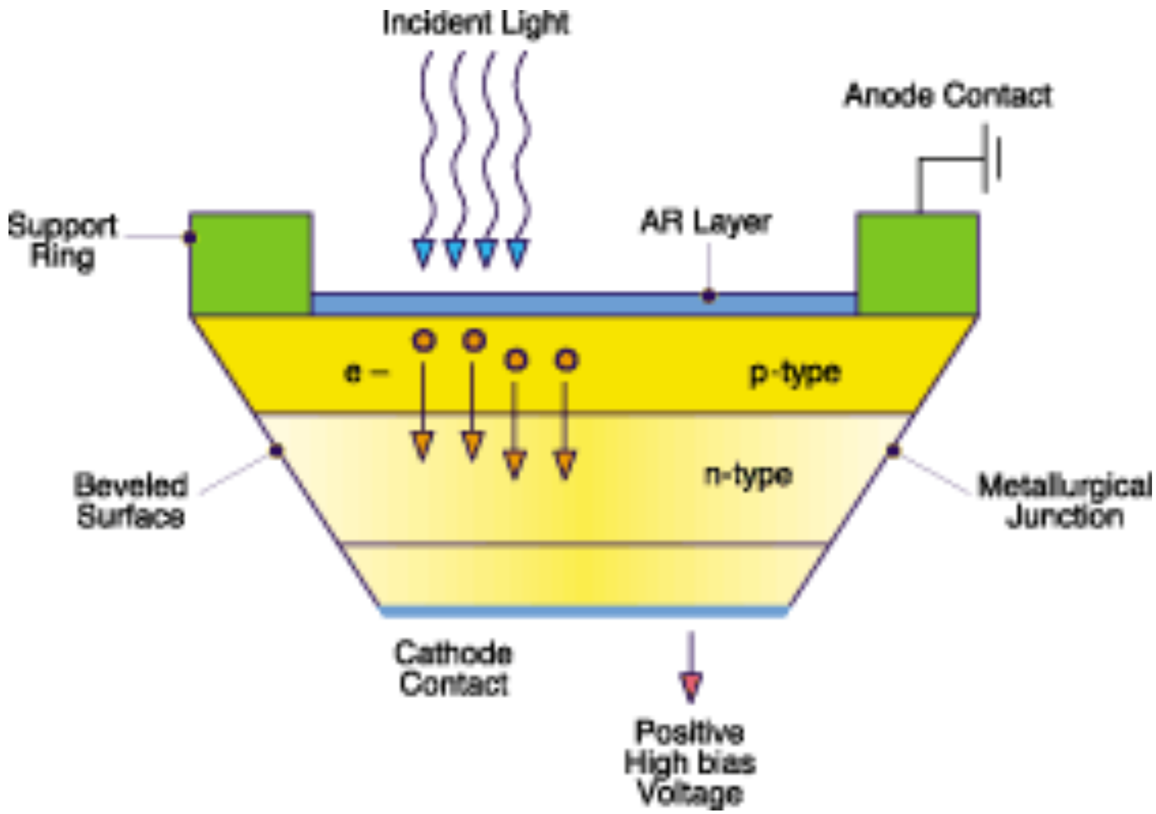
A photon creates an electron-hole pair, due to the concentration gradient there is a non-zero electric field in the depletion region which splits them before they can recombine. This movement of charge makes a detectable current. (i.e. e- into p region).

Using a reverse bias, the depletion region can be expanded improving performance

Photodetectors: Convert EM radiation into detectable electronic signal

Photodiodes (PDs)

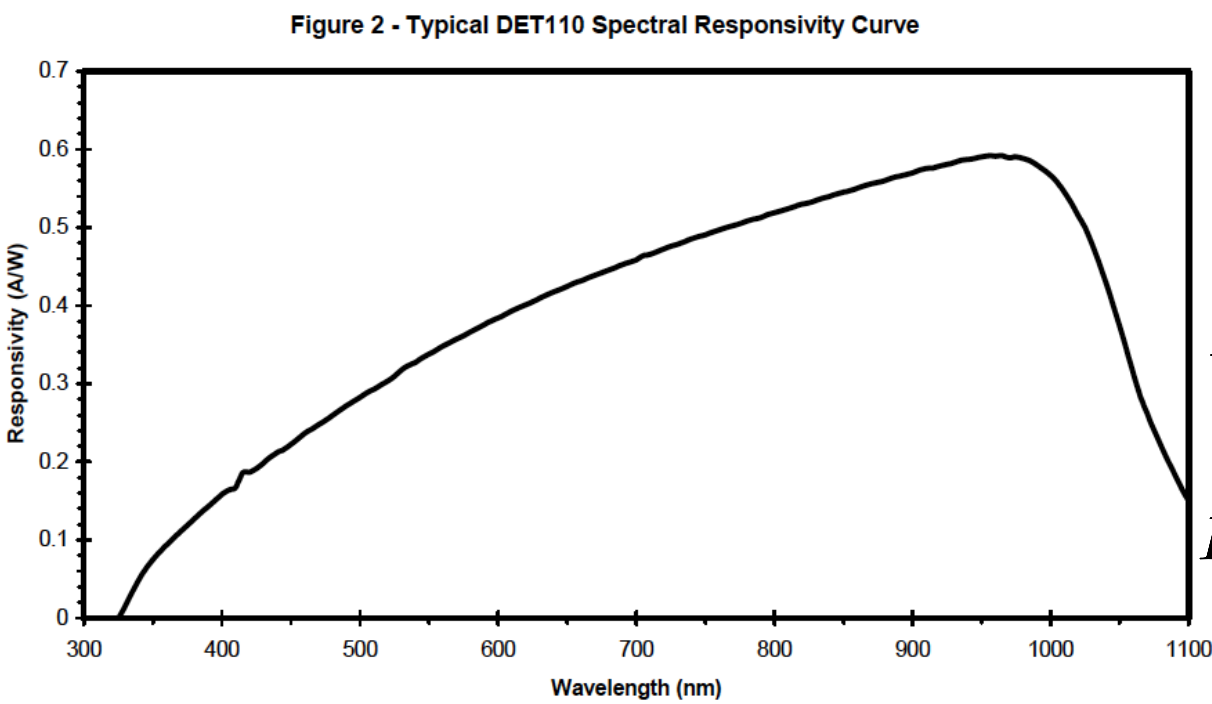
Avalanche Photodiodes (APDs)



Same principle, but a large voltage accelerates the produced electrons and leads to the production of secondary electrons. (Gains of ~1000)

Photodiode

- We will use photodiodes for most of the lab.
- To calibrate the signal they produce, look up the specs:



Suppose you measure:
1 V for 100 kOhm input impedance at 800 nm

R = 0.5 A/W

$$I_P = \frac{1\ \mathrm{V}}{100\ \mathrm{k}\Omega} = 10\ \mu\mathrm{A}$$

$$P_L = \frac{10\ \mu\mathrm{A}}{0.5\ \mathrm{A/W}} = 20\ \mu\mathrm{W}$$

Laser Safety

Website & Week 1 lab

- Website
- Week 1 lab
  - Prelab is due before you can do lab. This week TA will grade right before you start your lab.
- Week 2 Prelab due next Wednesday