Announcements

Reading:

Gregory, Chapter 27, to p. 576, pp. 581 to end
- Steven Weinberg, “The more comprehensible the universe is the more pointless it seems” (online)

Online evaluations open

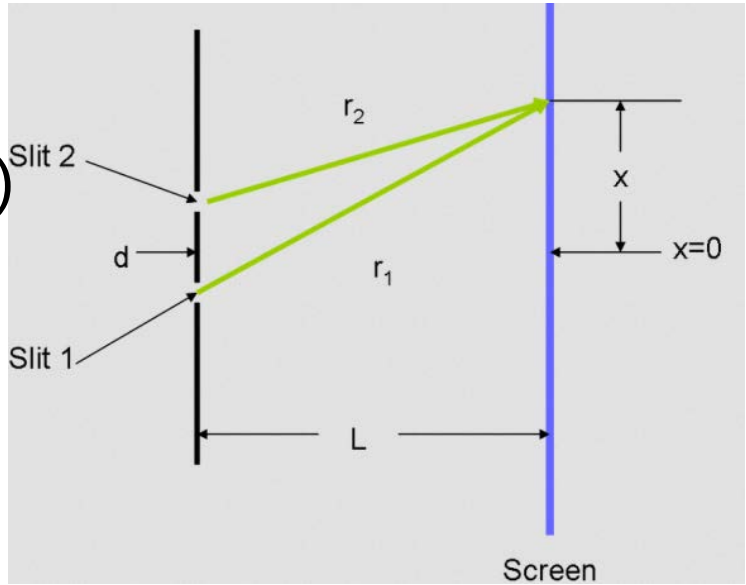
All grades except for Final to be posted on Canvas by weekend

Final exam

- Thursday, Dec. 15, 10:00 a.m. - 12:00 p.m., NPB 1002
- Comprehensive: covers entire course *but with emphasis (2/3) on material since midterm*
- Bring: ID, scratch paper (no calculator necessary). One "cheat sheet" with formulas allowed, handwritten front and back of 1 page
- Format: 30% mult. choice 40% short answer 30% essay (choice of 2)
- Review session 2nd part of class Tues next week, + during reading week TBA

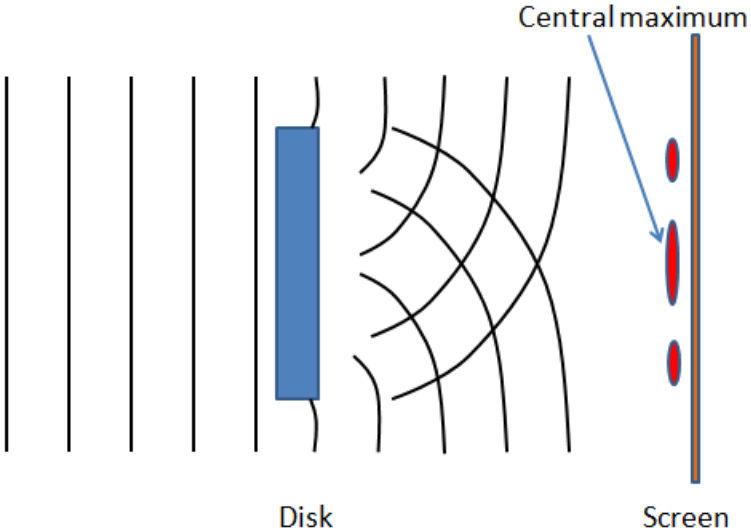
Remarks on HW 9

#1 a)



$$x = \frac{\lambda L}{d} = \frac{5\times10^{-7}\,m\cdot 2m}{1\times10^{-4}\,m} = 10^{-2}\,m$$

b) Why is there a central max?
(diffraction around a disk)



#4 Laplace's determinism did *not* rely on God

Last time (time before last)

- Photoelectric effect: minimum *energy* required for 1 photon to remove electron from a metal $\Rightarrow$ minimum frequency for photon (Einstein 1905)
- Bohr atom model (1913) accounted for Balmer spectrum (set of discrete frequencies) of hydrogen gas
- de Broglie: a particle is a wave $\lambda=h/p$
- Schroedinger and Heisenberg (1920s) constructed general framework of quantum mechanics
- Born: wave function ψ has probabilistic interpretation:

  $|\psi(x,t)|$ is probability of finding particle at x,t
- Wave-particle duality and role of observer in measurement

Bohr's atomic model was criticized by classical physicists, who believed

1. protons and electrons both had positive charge
2. atoms did not exist
3. the proton should orbit the electron, not vice versa
4. electrons did not exist
5. the atom would collapse because the accelerating electrons would radiate energy

Guest lecture Thursday

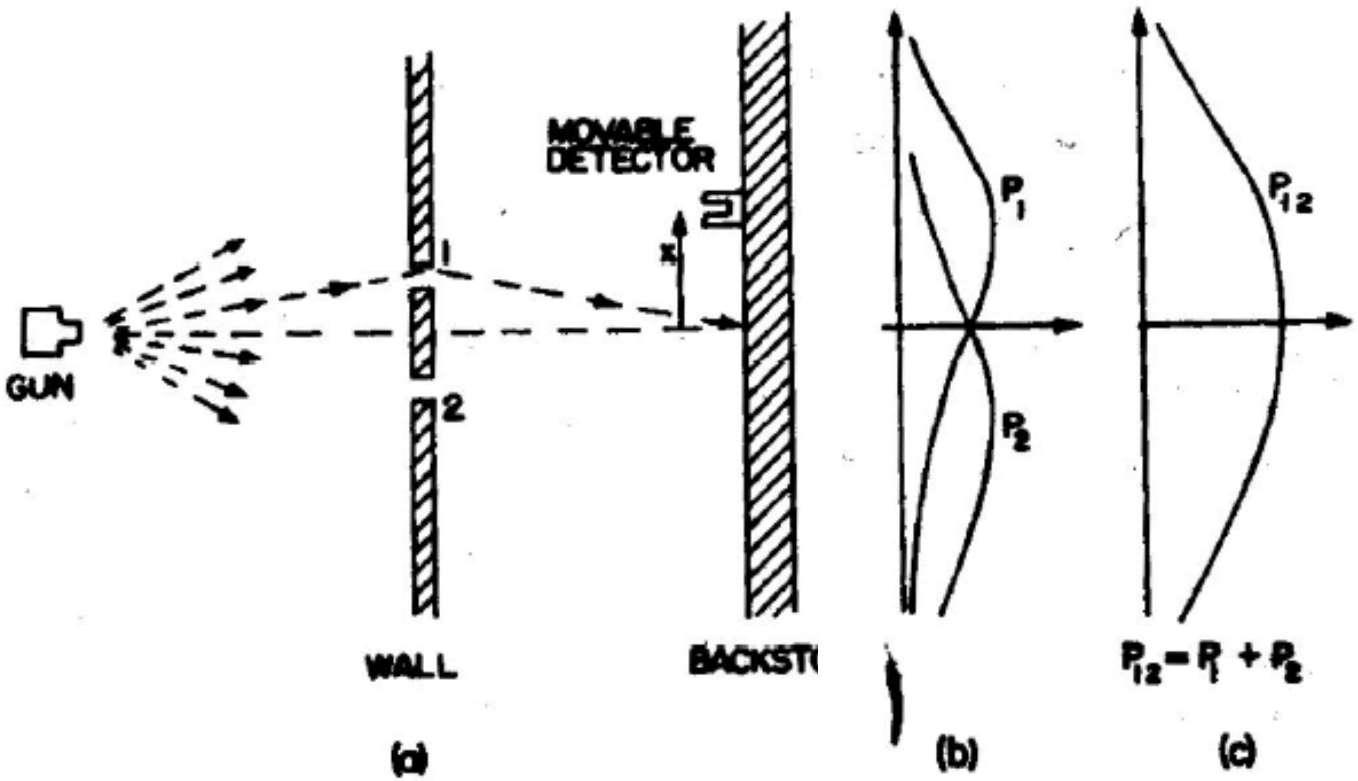
Guido Mueller, UF Physics

- Member of the LIGO team that detected gravitational waves predicted by Einstein's general theory of relativity last year!
- Will talk about general relativity, black holes, and gravitational waves.

Role of observer in quantum mechanics

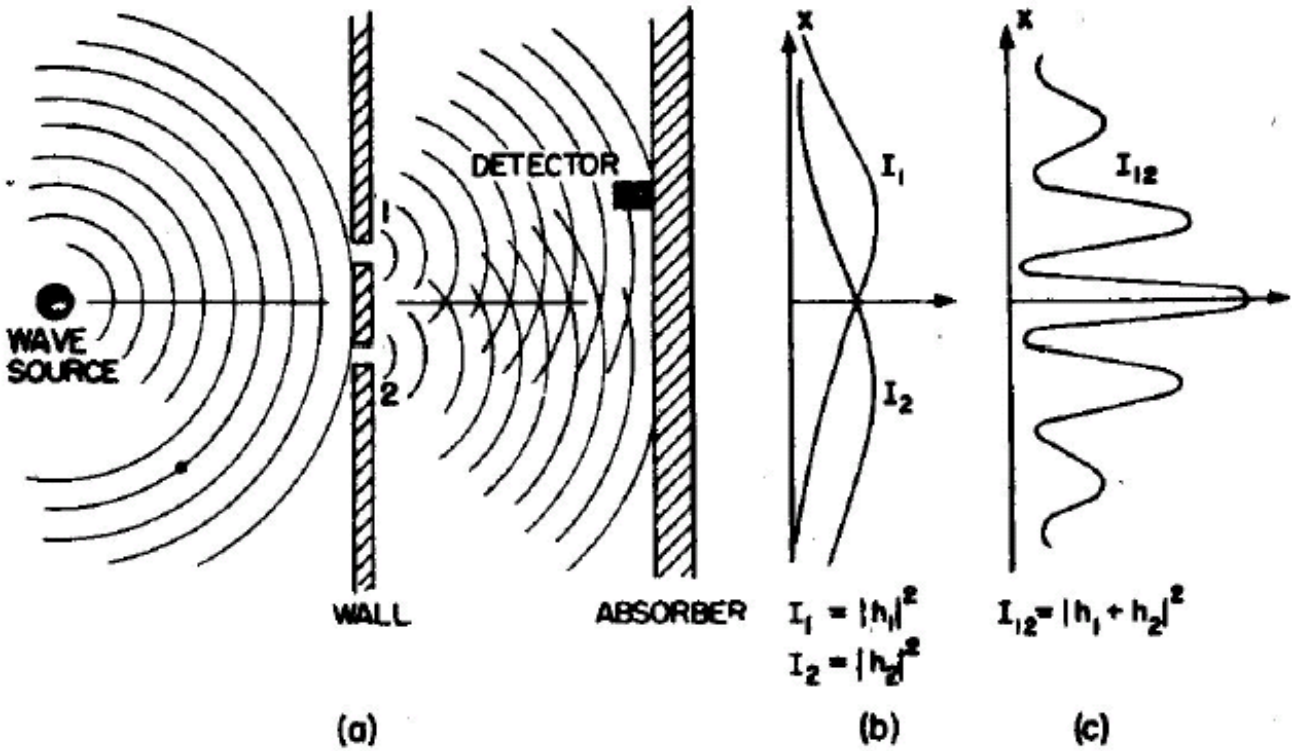
2-slit experiments with bullets (classical particles)

- Bullets always come in "lumps" -- identical size, mass particles.
- No interference: probability to arrive at screen is sum of probability to go through slit 1 and probability to go through slit 2, smooth distribution.



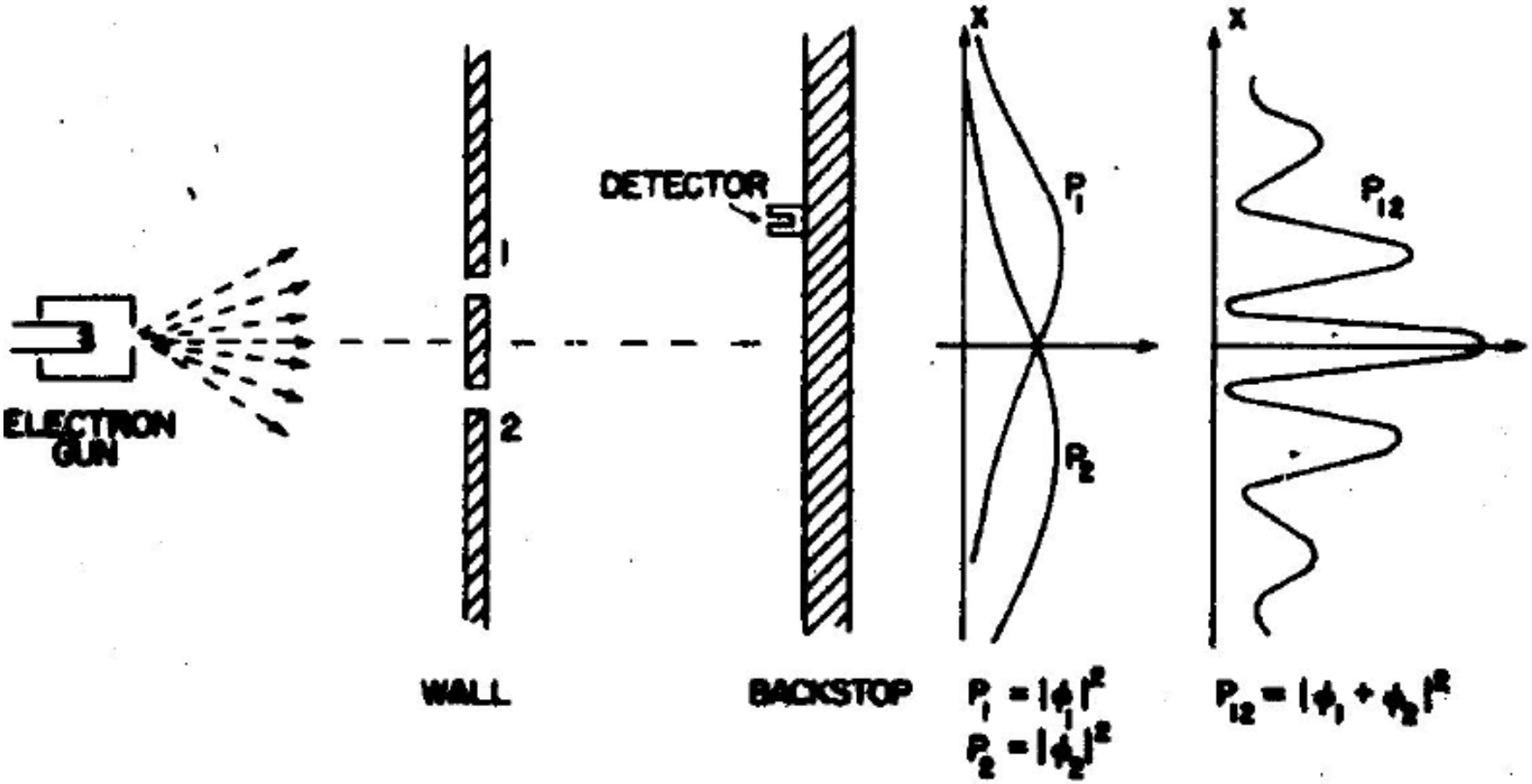
2-slit experiments with water (classical waves)

- Intensity of water waves propotional to height 2
- Intensity of waves reaching detector through slit 2 when slit 1 is closed is smooth, and vice versa.
- When two waves are allowed to pass through 1 and 2 at same time, interference pattern is created.



2-slit experiments with electrons (do they behave like bullets or waves?)

- Interference pattern observed by detector at screen



So--electrons are waves?

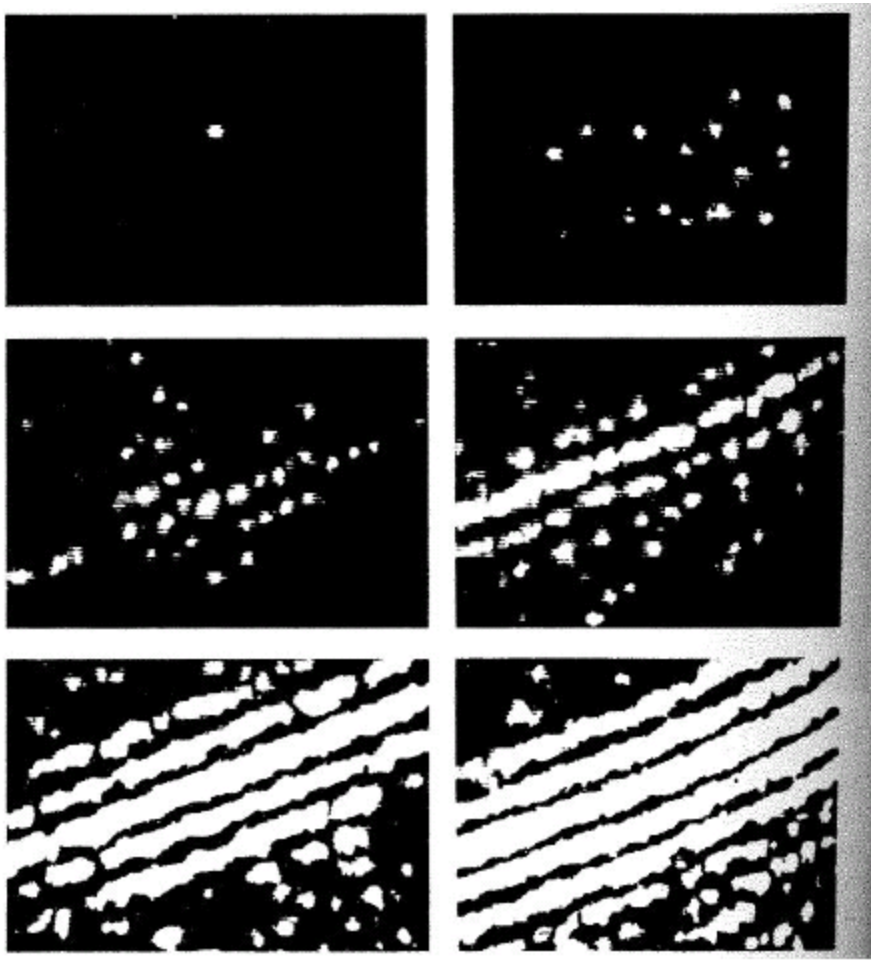
- Wait--we can slow gun down so that only 1 electron per hour goes through. Then we expect electron goes through slit 1 or 2, right? Every hour we get a new spot on the screen.
- Interference pattern builds up slowly:

So: electrons are "particle-waves"!

They exhibit properties of classical waves *and* particles

2-slit experiments with light

Weaken laser beam so that very few photons come out!

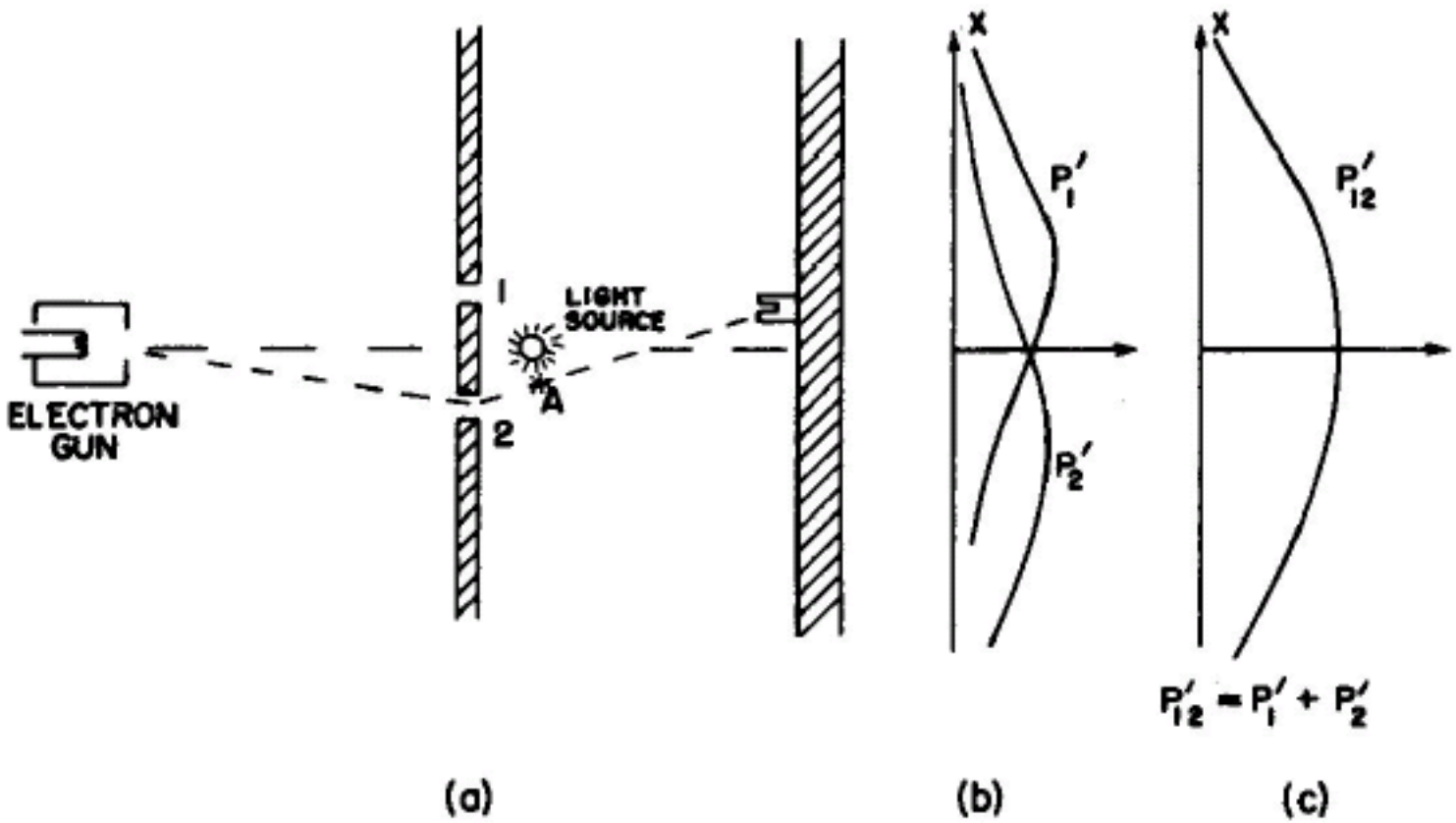


Light is "particle-wave" just like electrons!

(except photons move at speed of light, have no mass)

Observing which slit electrons go through I)

Wait a minute: if electrons can be seen to go through one slit or the other, how can they interfere with themselves? Let's try to determine which slit they pass through with a "camera"



Act of observation destroys interference pattern!

One way to say this: pinning down particle's position made momentum indeterminate!

Heisenberg uncertainty principle:

$$\Delta x \, \Delta p \approx \hbar$$

Planck's const. divided by 2π

uncertainty in your measurement of particle's *position*

uncertainty in your measurement of particle's *momentum*

Observing which slit electrons go through II)

Wait another minute! Maybe the light we used to observe the electron bumped it somehow, destroying interference. How about if we reduce the light's intensity or frequency?

• Reduce intensity: sometimes electron isn't observed--then it contributes to interference!

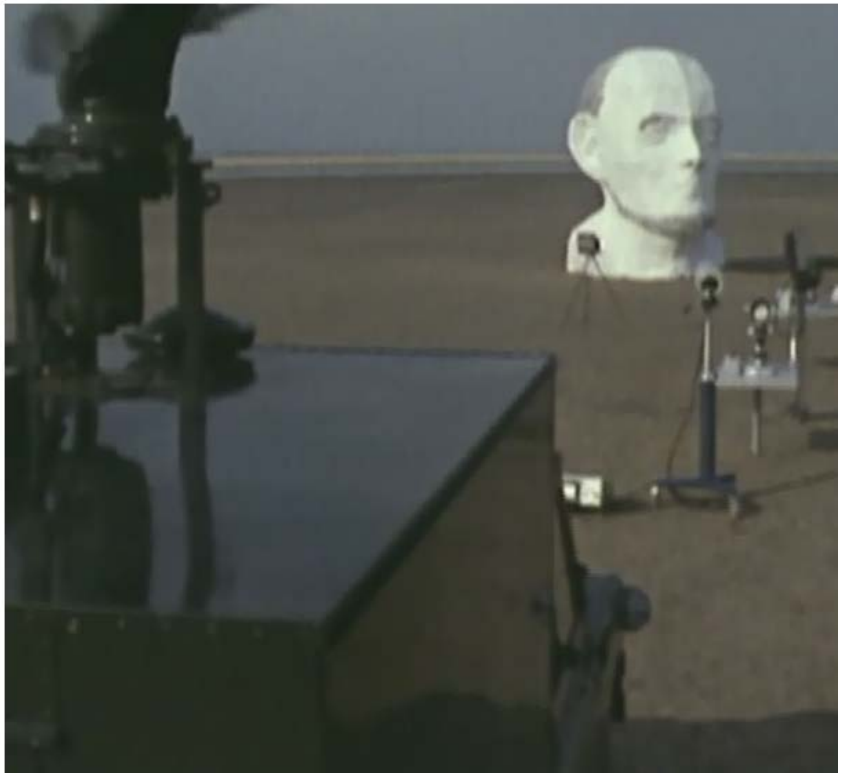
• Reduce frequency: oops! Remember we said you can't resolve anything smaller than the wavelength of light? When wavelength gets bigger than distance between slits, interference pattern comes back! Heisenberg again.

Conclusions:

●at small scales physics doesn't agree with our intuition. Rules of quantum mechanics predict results of all expts. so far, even if we have no "deeper" understanding.

●Particle is described by a "probability amplitude" to be somewhere. This is the probabilistic quantum reality.

Stefan Graziewicz



Face under short radio waves $\lambda = 0.1$ m

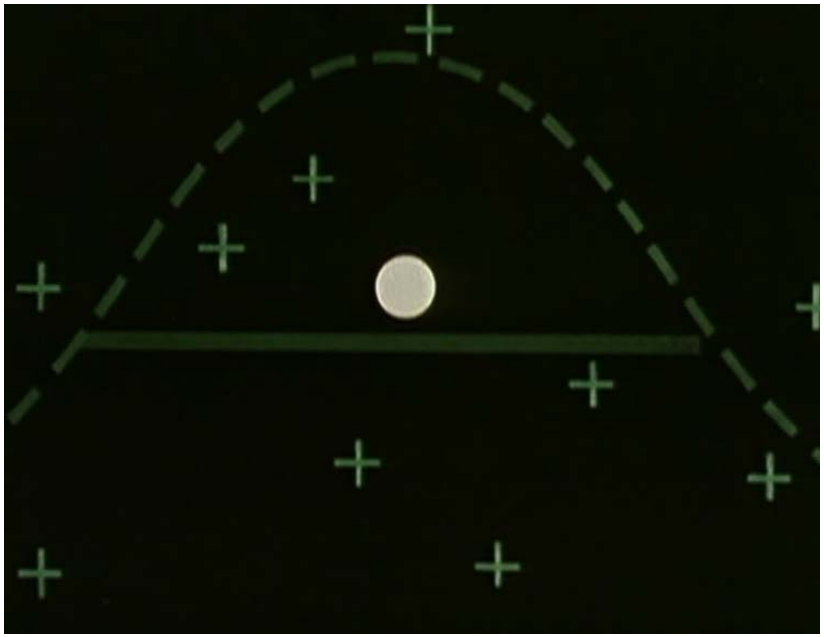
Face under infrared light $\lambda = 1000$ nm

Face under red visible light λ=300 nm

Electron microscope
$\lambda = h/p = 1$ nm

“A single atom of thorium—
still not a sharp outline”

Gaussian distribution



“object lies in an area of uncertainty”
(Bronowski -- `circle of tolerance’)

Gauss criticized Hegel, who claimed to have a philosophy that allowed conclusions more perfect than observation

Hegel “proved” the existence of only 7 planets; 8th was discovered

“The exchange of information can only take place within a certain tolerance”

“ All knowledge between human beings can only be exchanged within a framework of tolerance”

“Scientists were refining to the most exquisite precision the princ. O f tolerance & turning their backs on the fact that all around them Tolerance was crashing to the ground beyond repair”

Nazi racist anthropology

1933: Hitler destroys scholarship in Germany almost overnight”

Leo Szilard 1898-1964

Conceived of nuclear chain reaction (fission)

Concerned about Germans getting bomb, he organizes letter to Roosevelt, signed by Einstein (1939)

Fought to prevent nuclear knowledge from being used for warfare

Bronowski at Auschwitz:
Human dilemma: -- the belief that end justifies the means
-- “the assertion of dogma that closes the mind,
and turns a civilization into a nation of ghosts”

Bronowski closing remarks

"Science is a very human form of knowledge."

"Every judgement of science stands on the edge of error."

"It is a tribute to what we can know, although we are fallible"

Quotes O. Cromwell: `I beseech thee, in the bowels of Christ, think for a moment that you may be mistaken.'